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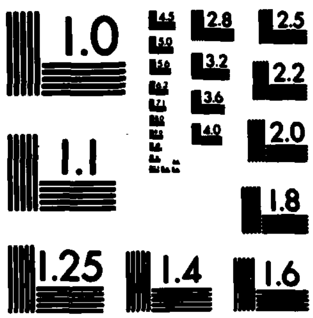

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USE OF DISJUNCTIVE RESPONSE REQUIREMENTS IN DUAL-TASK ENVIRONMENTS: IMPLICATIONS FOR AUTOMATION

BY

ROBERT J. SCHOEN

B.S., United States Air Force Academy, 1972

M.S., Purdue University, 1972

DISSERTATION

Submitted in Partial Fulfillment of the Requirements for the Degree of

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USE OF DISJUNCTIVE RESPONSE REQUIREMENTS IN DUAL-TASK ENVIRONMENTS: IMPLICATIONS FOR AUTOMATION

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Two experiments were conducted to assess the difference in resource requirements for choice and disjunctive (Donders Type c) responding in a dual-task environment. Experiment 1 utilized two binary tasks paired in all possible combinations of choice and disjunctive response requirements. For both tasks the disjunctive responses were faster and less error prone with the additional benefit of improving performance on the concurrent task. Experiment 2, using a primary-secondary dual-task paradigm, contrasted the resource cost of responding to the cost of not responding to stimuli that had varying degrees of similarity to the "go" stimuli. Results demonstrated a high degree of operator involvement in terms of resource use even when a response was not required. These results were discussed in terms of reducing operator workload within a semiautomated multitask environment by employing disjunctive responding in place of binary choice responding.

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INTRODUCTION

Continuing problems with human operators in complex control situations such as aircraft cockpits, nuclear power plants, and air traffic control centers necessitate continued research to find effective coping strategies for these multitask environments. In these multitask environments, the operator typically observes a large number of rapidly changing stimuli that may require a large number of discrete responses. In general, certain closely related sets of stimuli and responses define a given task although the overall degree of relationship often makes task boundaries difficult to define. Problems begin to appear as technological advances continue to supply ever increasing machine capabilities within each job function. The eventual result of these increased machine capabilities is operator overload, where the operator no longer has sufficient mental and physical resources to cope effectively with job requirements.

There are several possible avenues through which the problem of overload may be addressed. The first is a general human engineering approach (e.g., McCormick & Sanders, 1982; Van Cott & Kincaid, 1972) that attempts to improve the overload condition through improvements to workplace hardware. Improved, easily understood stimulus displays coupled with easily identifiable, less error-prone response devices can greatly simplify the workload condition. However, there are limits to these types of improvements as the individual tasks comprising the operator's job become increasingly complex. Another possible and now common solution is to automate certain portions of

the job, with the computer system assuming some of the responsibilities. Although complete automation may be an eventual best solution, it is often technologically, politically, or legally infeasible to do so especially when a job involves human safety and welfare (Weiner, 1980). The problem with automation then becomes one of deciding how much and what the operator will do. On the one extreme, the computer generates all the actions and the operator provides all the decisions. Unfortunately, this gains us little advantage in relieving the overload situation as the operator is still overburdened with decisions and excessive inputs. The other extreme is to automate to such a degree that the operator becomes a monitor. Now the operator becomes underloaded and suffers the boredom and lack of involvement present in many vigilance situations (Mackworth, 1969). The solution lies in finding some middle ground in which the operator is not overloaded with activities, yet is active enough to stay alert and involved in the functions of the system.

Although, as previously mentioned, the overload-underload problem has several facets, the types and numbers of responses required of the operator seems particularly significant in the eventual solution of the problem. The purpose of this research is to find a method that will aid in the overall problem of keeping an operator involved in the task, but not overloaded. Typically, an operator is faced with numerous stimuli each requiring a discrete response, for example, choice responding. Reduction in the number of required responses would possibly decrease workload, but it must be done without changing system output. An alternative to choice responding that appears

promising in accomplishing this objective is the use of disjunctive responses. Disjunctive responses are unique as they require a response to only one class of stimuli instead of individual responses to each of several stimuli required in the typical choice situation. In general, the class of stimuli requiring an overt response is called the "go" stimulus while all other stimuli are classified as "no-go." In a two stimuli situation, disjunctive responding replaces choice responding without any loss of information transmitted. Employed in a semiautomated system, a disjunctive response requirement would still demand the operator's involvement with the system, continuously monitoring for the stimulus requiring the response. At the same time, the total response demand is reduced as the system could automatically provide the response to a certain class of stimuli, most likely the more frequent event which does not require a more critical choice. The goal of this research is to examine the utility of disjunctive responding for use within a multitask environment.

The Disjunctive Response

Psychologists, from the time of Donders (1868/1969), have typically classified reaction time as being in one of three categories. Using the definitions originated by Donders, the types of reaction times are: simple reaction time (SRT), in which a single class of stimuli requires a certain response; choice reaction time (CRT), in which each of two or more classes of stimuli require a certain response; and disjunctive reaction time (DRT), in which two or more classes of stimuli may be presented, but only one requires a certain response.

The SRT is the fastest of the three tasks as only detection of the stimulus is necessary to initiate the response. The DRT is the next fastest, requiring discrimination between stimuli in addition to detection. CRT is the slowest, requiring response selection in addition to the other aforementioned processes. Although SRT is the fastest, it would have very limited applicability in a multitask, multiple-responses-per-task environment. As there is no decision required in the typical SRT situation, a design using multiple simple responses would needlessly overload the operator with detection-response sequences that could be fully automated.

It is important to ask if there is any indication that the DRT advantage maintains in situations where disjunctive responding could legitimately replace choice responding; that is, where only two classes of stimuli are the basis for the required decision. Hick (1952) found a 100 msec advantage when the number of stimuli is two for both the choice and disjunctive trials. This suggests that there does not have to be a change in the amount of information transmitted in order to realize the disjunctive speed advantage. This is important, as many real world tasks can often be dichotomized. Using an Air Traffic control example, the clearances issued to an inbound aircraft could be divided into aircraft requiring just the standard clearance or ones requiring some unusual clearance. A considerable savings in operator effort could be realized if an automated system issued the standard clearance unless interrupted by the controller, to issue a unique clearance when demanded by events. Although the disjunctive advantage is obvious in this macro example, the question

is if there is an advantage in changing to disjunctive responding in readily dichotomized, but more molecular situations. Modeled in the laboratory as a disjunctive task, it would eliminate one of the two responses without changing the overall result, but functionally require about the same amount of involvement with the task by the operator.

Of particular interest in the current research are the implications of the speed advantage of DRT over CRT. First discovered by Donders, and subsequently replicated (e.g., Hick, 1952; Rabbitt, Clancy, & Vyas, 1977; Woodworth & Schlosberg, 1954), the observed reaction time difference may indicate a difference in information processing resource use. However, before recommending any changes in response requirements to disjunctive, it must be determined whether the savings in either time or operator resources warrant the switch. The typical 100 msec DRT advantage may, by itself, be of little use for direct application. Conversely, the 20% to 30% (Donders, 1868/1969) time savings it represents in the typical laboratory study, if translated to a real world task, could result in significant time savings. More important, the time advantage introduces the possibility that a disjunctive task is less resource demanding than a choice task. Reduced resource use would suggest the possibility that non-used resources may be available for other tasks, indicating that time savings are possible in concurrent tasks as well.

In order to address the resource issue, it will first be necessary to test whether the DRT advantage maintains in a dual-task paradigm. The dual-task paradigm, described in Kerr (1973), requires the

simultaneous performance of two tasks. If the tasks require common resources and are in the resource-limited region (Norman & Bobrow, 1975), task performance, as measured by response speed, should decrease for one or both tasks when they are combined. This decrease in performance is called dual-task interference, and indicates that the demand for resources exceeds their availability. As previously mentioned, the DRT speed advantage is clearly supported in the single-task literature, but there is only the implication that reduced response time indicates reduced resource use. As task accomplishment may vary in duration but demand a set amount of resources (Navon & Gopher, 1979), determining a time-resource relationship in a single-task paradigm is difficult. However, using a dual-task procedure it is possible to measure both reaction time and examine changes in the performance of a concurrent task, possibly giving support to a time-resource relationship. Currently there is no direct evidence which supports the robustness of the DRT speed advantage in the multitask environment, although Comstock (1973) found the SRT-DRT speed difference originally established by Donders (1868/1969) in a single-task paradigm, was maintained in a dual-task paradigm.

If the DRT speed advantage is maintained within the planned dual-task experimentation, then it will be possible to ascertain any difference in resource demand between CRT and DRT. Given that there are differences, the overall importance of resource use may depend on where in the stimulus-response sequence the difference exists. If a change to disjunctive responding results in resource savings across all aspects of the information processing sequence, significant

improvements might be expected on concurrent task performance.[1] If the locus of the advantage lies in only the response stages of processing, smaller gains might be expected and meaningful application might be limited to situations in which there are nearly simultaneous response requirements for several tasks. By the same token, if the DRT speed advantage is limited to the response stage, it would indicate that functionally equivalent encoding processes are occurring in CRT and DRT, connoting the same degree of operator involvement in the non-response aspects of the task. What remains to be determined is where in the information processing sequence the DRT advantage lies.

Past research employing disjunctive response requirements, using single-task paradigms, have emphasized the response portion of the encoding-central processing-responding sequence as the locus of the DRT speed advantage (Donders, 1868/1969; Hick, 1952; Rabbitt et al., 1977). There is a considerable literature indicating that when a choice must be made between two discrete responses, a large proportion of the total response time from stimulus presentation to response execution is involved in the response selection process (Broadbent & Gregory, 1962; Donders 1868/1969; Hick, 1952; Keele, 1973; Rabbitt et al., 1977). Donders' hypothesis is illustrative of this position as he posited the lack of a response selection stage in disjunctive responding as the reason for the 100 msec advantage. Although more latter day theorists (Kantowitz, 1974; Kantowitz & Knight, 1974, 1976; Keele, 1973) tend to subdivide the response stage into a preparation, selection, initiation, and execution sequence, they, too, are in fundamental agreement with Donders. If there are savings in a

disjunctive task over a choice task occurring in stages other than the response stage, more efficient use of disjunctive response requirements are possible as all processing stages may be using less resources.

There are several reasons for questioning the assumption that the locus of the DRT advantage lies exclusively within the response stage. First, this position assumes that Sternberg (1969) and Pachella (1974) have called pure insertion; that is, no other information processes are affected by a change in response requirements. Other researchers (Egeth, Marcus, & Bevan, 1972; Pachella, 1974), investigating the effects of disjunctive and choice response requirements, have found evidence indicating changes in the encoding processes as a result of response requirement changes. Second, on logical grounds it may be asked if only the response selection processes are involved, what is the difference in selecting between two choices, go and no-go, and two choices, A or B? Finally, the strong response-only position does not take into account additional factors that may also influence reaction time differences (e.g., subject response strategies).

Grice and his colleagues (Grice, Canham, & Schafer, 1982; Grice, Hunt, Kushner, & Nullmeyer, 1976; Grice, Nullmeyer, & Spiker, 1982; Spiker, 1978) and Nickerson (1971) have found that there are large differences in obtained DRTs relative to CRTs depending on both type of task (e.g., tone discrimination versus letter identification in a flanker task) and subject strategy (e.g., what Grice calls associative and detection strategies). Grice found that DRT response values can

range between the normal values obtained for SRT and CRT. Nickerson, using a difficult discrimination task, actually found DRT times slower than CRT times for the same task. It is therefore improbable that the strong response-only position adequately explains the actual difference between disjunctive and choice responding.

If the use of disjunctive responses simplifies other stages of processing as well, the total amount of released resources may result in more generalized performance improvements in concurrent tasks. However, further consideration needs to be given to the substitutability of disjunctive for choice. It would be important to know whether or not task involvement was being maintained if there were substantial changes in encoding as well as responding (see Price, 1985; Weiner, 1985). A lack of resources expended at encoding and central processing in the disjunctive situation may indicate a lesser degree of involvement with the task. Although low error rates give some indication of task involvement, evidence of significant resource use at encoding in a disjunctive task would provide strong converging evidence. Therefore, an assessment of resources demanded at encoding is required both to address the theoretical question of the locus of the DRT speed advantage as well as provide evidence of task involvement.

To summarize, this research investigates some questions about response requirements as they relate to the more general issue of operator workload. It is proposed that the use of disjunctive responses may reduce the operator workload by decreasing response requirements while allowing the same amount of operator involvement

with other aspects of the task. Of primary interest is the possible reduction in workload engendered by a change to disjunctive responding in short time span work environments where an operator is apt to be overloaded. There are several issues about disjunctive responding that need to be answered within a simplified laboratory situation in order to ascertain whether employing it in such work environments would be justified. First, does the DRT advantage maintain in a dual-task situation? Second, does disjunctive responding free resources that may be used for another task? Third, are other processes such as encoding equally demanding in the disjunctive situation, so that operator involvement with the task can be maintained? Answers to these questions are necessary before the usefulness of employing disjunctive response requirements in a multitask environment would be warranted.

The primary objective of Experiment 1 is to determine the robustness of the DRT advantage and examine resource demands in a dual-task situation. Assuming that a disjunctive task reduces resource demand, Experiment 2 addresses the issue of the locus of the DRT speed advantage using a primary-secondary, dual-task procedure. Together, these experiments give a clear indication of the usefulness of this particular response requirement manipulation towards solving the larger issue of operator workloads in multitask environments. A further description of the methodologies and issues to be explored by each experiment will be given in the context of the individual experiment descriptions.

Note

[1] This assumes a human information system as modeled by Navon and Gopher (1979) and Wickens (1983) which hypothesize several independent and non-transferable resource pools. If the system is more like Kahneman's (1973) single undifferentiated resource pool, then any resource savings anywhere within the system could be used anywhere else in the system. The former position is assumed as being more conservative in measuring the possible results.

EXPERIMENT 1

The aims of Experiment 1 were first, to determine whether there was a speed advantage for DRT over CRT in a dual-task situation, and second, to determine whether a DRT task demands less resources than a CRT task. The two tasks making up the dual-task situation were a two-choice letter classification task and a two-tone discrimination task. As both tasks each had only two possible responses, a disjunctive response replaces the normal choice response condition without any loss of transmitted information. Thus, the primary manipulation was changing the response requirements on one or both tasks from choice to disjunctive and analyzing the response time (RT) changes on both tasks.

The RTs for each task were measured in dual- and single-task environments. For the dual-task trials, a choice or disjunctive tone task was paired with a choice or disjunctive letter task resulting in four possible pairings. As the stimuli for the two tasks were presented either simultaneously (coincident) or alone (non-coincident), dual-task RTs could be subdivided accordingly. Coincident events, however, have inherent structural response conflicts (Kahneman, 1973) that lead to unpredictable response ordering and, as a result, confounded response times. Non-coincident events, though, in which the concurrent task was expected but does not occur, do not have the problems created by a simultaneous demand for responses. As a result, non-coincident dual-task RTs provided the more stable and more conservative data used for comparative purposes.

The single-task (ST) response times were used as a baseline measure. Consistently faster RTs in the ST situation (e.g., a faster disjunctive response to the letter task alone than when paired with the tone task) would indicate that there is dual-task interference (Kerr, 1973) and that both tasks are within the resource-limited region of processing (Norman & Bobrow, 1975). Stated in another manner, the faster ST response times would indicate that simultaneous task performance demands more total common resources than are available. With this situation it was then possible to measure the changes in resource availability as a consequence of changes in task structure (e.g., response requirements) by examining performance changes on both tasks (see Ogden, Martin, & Paap, 1980).

Assuming that a disjunctive response requires less resources, there were several possible outcomes from the dual-task comparisons. First, if the letter and tone tasks demand common resources or if there is a cost of concurrence in executing them both simultaneously (see Navon & Gopher, 1979), either task may be pushed further into the resource-limited region of processing (Norman & Bobrow, 1975). As the resource demand/response time relationship may be non-linear, the resulting difference between DRT and CRT in a dual-task environment may be even greater than the difference observed in a single-task comparison. Second, RTs may also be influenced by resource reallocation. Given that the letter and tone tasks share resources across CRT and DRT tasks, additional changes in RTs may result from subjects shifting resources away from the easier task (Johnson, Forester, Calderwood, & Weisgerber, 1983). In this case, changing

from choice to disjunctive on one of the tasks would not only decrease the RT on that task, but also result in faster RTs on the concurrent task. Conversely, if resources are not shared, then only the task changing from choice to disjunctive would show any improvement in RT if, in fact, disjunctive tasks are less resource demanding.

Method

Subjects. Sixteen students from introductory psychology classes at the University of New Mexico participated in this experiment for extra credit towards their course grades as well as a cash incentive of $10. All subjects participated in four 1-hour sessions. These four sessions were completed in a maximum of 8 days with no two sessions more than 3 days apart.

A total of four subjects were eliminated from the experiment. Two subjects were dismissed for hearing deficiencies. The third subject was eliminated on the first day for failure to comply with instructions. The fourth subject was eliminated on the third day after reporting a loss of interest in the experiment corroborated by a sudden jump to a 30% error rate.

Apparatus and stimuli. All measurement of reaction times and presentation of stimuli were carried out by a Terak 8510 microcomputer. Presentation of the tones (60 db, 500 and 1000 Hz) was through Koss K-6 stereo headphones. The letters used in the letter classification task were presented on the Terak computer screen as white letters on a dark background. The letters "X" and "O" were used in the letter discrimination task, measuring 2.5 mm in width and 4.5 mm in height. The subjects sat facing the computer screen at an approximate distance

of 92 cm. Each letter subtended approximately 0.62 degrees of visual angle in height and 0.44 degrees in width. A visual fixation square defined by four "+" signs was continuously displayed in the center of the screen except when replaced by a feedback display. Specially marked keys on a standard keyboard were used to respond to both tasks. Adjacent keys on the lower left side of the keyboard, marked X and O, were used to respond to the letter classification task. Adjacent keys on the lower right side of the keyboard, marked H and L for high and low, were used to respond to the tone task. When the session included disjunctive tasks, only the appropriate key, H for the tone task or X for the letter task, was marked and active.

Design and procedure. In the following discussion, "L" and "T" are used to designate the letter and tone tasks respectively. As each task can be assigned either a choice or disjunctive response requirement, the type of response is designated as DRT or CRT. For example, the response times for a letter task with a disjunctive response requirement paired with a tone task with a choice response requirement is designated as DRT(L)/CRT(T). RTs were collected from each of the eight conditions defined by the four possible pairings in which each subject participated: CRT(L)/CRT(T), CRT(L)/DRT(T), DRT(L)/CRT(T), and DRT(L)/DRT(T). All subjects received these pairings in a different order, based on a Latin Squares design in which four of a possible six squares were used. Additionally, RTs were measured for tasks L and T individually. In this single-task situation, ST was added to the designation. For example, a disjunctive, letter, single-task response time would be DRT(L)-ST.

In conditions DRT(L)/DRT(T) and CRT(L)/DRT(T) that require a disjunctive response to the tone task, the go-tone (requiring the response) was the high tone. In conditions DRT(L)/DRT(T) and DRT(L)/CRT(T) which require a disjunctive response to the letter classification task, the go-letter was X. The X and H response keys were operated by the subject's index fingers.

In order to realize the analytical advantages of the dual-task paradigm, it was necessary to maintain, as much as possible, a constant allocation of resources to the two tasks over the duration of a trial. To minimize within-trial resource reallocation between the two tasks, the temporal onset of the tones and letters was determined independently. The presentation of these stimulus events was a random occurrence within a specified interval of time. This procedure was intended to encourage consistent resource allocation by removing sequential and temporal cues.

A trial was a 160 sec time segment. During a dual-task trial, a subject was presented 16 letter-only identification events (non-coincident), 16 tone-only discrimination events (non-coincident), and 32 letter plus tone events (coincident). The average time between stimulus presentations was 2.5 secs, with a range from 2.0 to 3.0 secs in 250 msec steps. On the letter identification task, the letter X or O appeared centered within the confines of the fixation square for 500 msec. On the tone task, a 500 Hz or 1000 Hz tone sounded for 500 msec. When a task required a disjunctive response, one-half of the stimuli presented required a response. Subjects were allowed a maximum response time of 2 secs with all longer responses counting as

errors. Feedback consisting of percent correct for both the tone task and the letter classification task as well as the average RT for each task was provided after each trial.

Each experimental session consisted of a practice single-task baseline trial per task, an experimental single-task baseline for each task, two dual-task practice trials, and seven experimental dual-task trials. The single-task baseline trials, DRT(L)-ST, CRT(L)-ST, DRT(T)-ST, or CRT(T)-ST, were presented in counterbalanced order with subjects practicing the appropriate responses for the current response conditions. Separate instructions were presented for the individual task trials and the dual-task trials (see Appendix II-A). Single-task letter classification and tone trials were presented in the same manner as described above except that a trial included only 48 stimulus presentations. These 48 stimulus presentations were of only one task and had the same average 2.5 sec separation as in dual-task trials. After each single-task trial, subjects were provided their average response time and errors. The two trials of dual-task practice were the same as actual experimental trials. Subjects were instructed to give equal emphasis to responding as quickly and accurately as possible to both tasks.

Results and Discussion

The major assumptions and hypotheses were: (1) to demonstrate the existence of dual-task cost (Kerr, 1973) that would put the task in the resource-limited region of processing (Norman & Bobrow, 1975); (2) to ascertain whether or not the DRT speed advantage was maintained across single- and dual-task environments; and (3) to determine if

resources are shifted away from a disjunctive task to the benefit of the concurrent task. As hypothesized, the DRT speed advantage did maintain within the dual-task environment with a demonstrated dual-task cost. Moreover, resources are shifted away from disjunctive tasks.

As this experiment transpired over four sessions, a test was first run to determine if there were significant practice effects. Table 1 shows the collapsed mean RT and error rate for all dual-task responses. Although RTs for Days 3 and 4 appear to decline, the difference was not significant, $F(3, 45) = 0.32$, $p = .81$ (see Appendix III-A, Table 6). As there was no significant effect of practice over days, days was removed as a factor and all subsequent analyses averaged data across days.

Table 1

Mean Composite Dual-Task Response Times (msec) and Error Rate (%) by Day (Experiment 1)

	Day 1	Day 2	Day 3	Day 4
RT	632	631	610	603
Error Rate	0.96	1.40	0.96	0.95

The very low error rates observed across all experimental conditions are summarized on Tables 2 and 3. The positive correlation between error rates and RTs eliminates any concern about a speed-accuracy trade-off adversely biasing the conclusions reached through

Table 2

Mean Tone Task RTs (msec) and Error Rates (%) for Choice and Disjunctive Responding in Single (ST) and Dual (DT) Task Environments (Experiment 1)

Task Type	RT	Error Rate
ST-DRT	357.9 (59.6)	0 (0)
DT-DRT		
Coincident	594.6 (66.5)	0.32 (0.4)
With CRT letter task	650.2 (76.0)	0.36 (0.5)
With DRT letter task	539.0 (71.3)	0.28 (0.5)
Non-coincident	519.7 (76.2)	0.17 (0.4)
With CRT letter task	548.9 (75.3)	0.11 (0.3)
With DRT letter task	490.5 (84.0)	0.22 (0.7)
Overall	579.6 (65.3)	0.29 (0.3)
ST-CRT	383.3 (41.3)	1.43 (2.1)
DT-CRT		
Coincident	685.6 (76.8)	2.34 (1.5)
With CRT letter task	781.8 (117.9)	2.62 (1.8)
With DRT letter task	589.5 (47.1)	2.07 (1.4)
Non-coincident	574.8 (70.0)	1.51 (1.8)
With CRT letter task	617.1 (110.1)	1.67 (2.5)
With DRT letter task	532.6 (55.3)	1.34 (2.1)
Overall	663.5 (73.5)	2.18 (1.3)

Note. *SDs* presented in parentheses.

Table 3

Mean Letter Task TRs (msec) and Error Rates (%) for Choice and Disjunctive Responding in Single (ST) and Dual (DT) Task Environments (Experiment 1)

Task Type	RT	Error Rate
ST-DRT	237.3 (25.5)	0.52 (1.2)
DT-DRT		
Coincident	570.7 (75.1)	0.35 (1.0
With CRT tone task	632.2 (81.9)	0.17 (0.3)
With DRT tone task	509.2 (82.8)	0.53 (1.8)
Non-coincident	452.5 (51.0)	0.56 (1.0)
With CRT tone task	495.8 (60.1)	0.17 (0.5)
With DRT tone task	409.3 (53.3)	0.95 (2.0)
Overall	547.0 (68.4)	0.39 (1.0)
ST-CRT	310.3 (31.3)	1.43 (1.8)
DT-CRT		
Coincident	625.7 (100.5)	1.26 (1.3)
With CRT tone task	690.9 (128.0)	1.45 (1.8)
With DRT tone task	560.5 (89.0)	1.06 (1.2)
Non-coincident	487.3 (52.7)	1.40 (1.5)
With CRT tone task	525.4 (69.5)	1.56 (2.1)
With DRT tone task	449.2 (75.3)	1.23 (1.8)
Overall	598.0 (88.3)	1.28 (1.2)

Note. *SDs* presented in parentheses.

comparison of the RTs. Therefore, the remaining analyses will be based on RTs alone.

Dual-task cost. Subject RTs for choice and disjunctive responding in the single- and dual-task environments are summarized on Tables 2 and 3. Using the non-coincident times for dual-task, the CRT for a single-task tone (M = 383.3 msec) is less than the CRT for a dual-task tone (M = 574.8 msec), $t(15) = -11.83$, $p < .001$. Similarly, the disjunctive tone RTs are less for single-task (M = 357.9 msec) than for dual-task (M = 519.7 msec), $t = -13.66$, $p < .001$. Turning to the letter task, CRTs are again less for single-task (M = 310.3 msec) than for dual-task (M = 487.3 msec), $t(15) = -15.79$, $p < .001$. Finally, letter task DRTs are less for single-task (M = 237.3 msec) than for dual-task (M = 452.5 msec), $t(15) = -19.21$, $p < .001$. (The adjusted alpha levels for these t tests is .006.) Taken together, these t tests indicate a significant dual-task cost (Kerr, 1973). It is therefore clear that the tone and letter tasks were in the resource-limited region of processing (Norman & Bobrow, 1975) during dual-task trials. The analysis of the coincident RTs, despite the response conflict problems, showed the same pattern of findings, all p's < .001.

DRT speed advantage. From Tables 2 and 3, it can be seen that single-task mean RTs were faster for the disjunctive task than the choice task on both the tone task (25 msec), $t(15) = 2.39$, $p = .031$, and the letter task (73 msec), $t(15) = 3.33$, $p < .001$. Although these results show a DRT speed advantage, the magnitude of the effect is less than what is usually reported. For example, Hick (1952), within

a single-task setting, found a disjunctive speed advantage of 100 msec. However, Grice and his colleagues have demonstrated a great deal of variability in the magnitude of the effect depending upon the type of task (Grice, Canham, & Schafer, 1982; Grice, Hunt, Kusher, & Nullmeyer, 1976; Grice, Nullmeyer, & Spiker, 1982).

Given the presence of a DRT speed advantage in a single-task environment, the question now arises as to whether this effect is maintained in a dual-task environment. Looking first at the non-coincident RTs for the tone and letter tasks on Tables 2 and 3, it can be seen that there are respective 55 msec and 35 msec DRT speed advantages. (As these tasks were analyzed together in a 2 x 2 x 2 ANOVA [Task x CRT/DRT x CRT/DRT Concurrent Task], marginal means for the main effects are also presented on Table 4.) The main effect of a DRT speed advantage is significant, $\underline{F}(1, 15) = 22.08$, $\underline{p} < .001$ (see Appendix III-A, Table 7).

Similar results were obtained from an analysis of the coincident RTs. Referring to Tables 2 and 3, the tone and letter DRT speed advantages are 91 msec and 55 msec. Again, the main effect of a DRT speed advantage is significant, $\underline{F}(1, 15) = 39.68$, $\underline{p} < .001$ (see Appendix III-A, Table 8). Further examination of Appendix III-A, Table 8, although showing no significant two-way interactions, does reveal a significant three-way interaction for the ANOVA for coincident trials. An examination of the simple two-way interactions by task, though, exposed a response conflict that resulted in extraordinarily long tone CRTs in the presence of a CRT letter response demand, the resulting interaction does not seriously

Table 4

Marginal Means (msec) for 2 x 2 x 2 ANOVA--
Non-coincident Analysis (Experiment 1)

Main Effect	Mean
Task	
Tone	640.3
Letter	598.3
CRT/DRT response	
CRT	656.0
DRT	582.5
CRT/DRT concurrent task	
With CRT	688.8
With DRT	549.8

compromise the main effect results. Therefore, the hypothesis that the DRT speed advantage will maintain in the dual-task environment is supported.

The DRT speed advantage from single- to dual-tasks appeared to interact with the criterion variable. For the letter task, the single-task DRT speed advantage is 73 msec compared to a 35 msec speed advantage for non-coincident dual-task. However, for the tone task, the DRT speed advantage is larger in the non-coincident dual-task (55 msec) than in the single-task (25 msec). The conclusion reached in light of these contradictory data is that the DRT advantage is robust enough to maintain within the dual-task environment, but may not be the same magnitude of effect as observed in the single-task environment due to the nature of the task, the nature of the concurrent task, and/or particular subject differential resource allocation strategies.

Resource shifting. The final hypothesis considered in the present experiment investigated whether the disjunctive task is less resource demanding than the choice task. If the disjunctive response does require less resources and these resources may be shared with the concurrent task, we can expect that the performance on the concurrent task will be superior when paired with a disjunctive as opposed to choice task. Examination of Tables 2 and 3 for non-coincident trials shows a consistent RT advantage for having a disjunctive concurrent task. This advantage is 58 msec for a disjunctive tone task, 85 msec for a choice tone task, 87 msec for a disjunctive letter task, and 76 msec for a choice letter task. Referring again to Table 4 for the

marginal means, the main effect for concurrent task pairings is significant, $F(1, 15) = 57.13$, $p < .001$, with the advantage being in having a disjunctive concurrent task (see Appendix III-A, Table 7). Examination of the coincident trials shows the same pattern as reported above with the relative advantage for having a disjunctive concurrent task ranging from 111 to 192 msecs, $F(1, 15) = 131.94$, $p < .001$ (see Appendix III-A, Table 8). Again, the presence of the three-way interaction for the ANOVA for coincident trials does not seriously compromise the main effect results.

The details of the resource shifting issue also bear closer examination. Regardless of the response requirements of the tone or letter tasks, response times improved significantly when the task was paired with a disjunctive concurrent task. As demonstrated by examination of the non-coincident tone and letter task events, this shift in resources appears permanent within a given combination of tasks. This was despite the fact that only a single response was required in the non-coincident trials and the other task, when presented, was in a different modality. Still, there was a shift in resources. Whether any additional shifting of resources occurs when the tasks are coincident is difficult to determine due to the confounds introduced by the structural response constraints not present in non-coincident trials. As a point of interest, however, DRTs computed as a percentage of CRTs are less for coincident events for both disjunctive (6%) and choice (11%) tone tasks. Similarly, coincident DRT percentages are less than non-coincident DRT percentages for both the choice (4%) and disjunctive (2%) letter

tasks. That is, when a response is demanded for both tasks (coincident), the advantage in having a DRT concurrent task is proportionally better than when the concurrent task was expected but did not occur (non-coincident), which suggests that some additional resource shifting may have occurred.

EXPERIMENT 2

Earlier it was noted that the use of disjunctive response requirements may represent a possible solution to some workload problems. It was argued that a change to disjunctive would be justified if there was not only a time and/or resource savings as indicated by the results of Experiment 1, but an indication that the amount of task involvement by the operator was sufficient to enable fast, appropriate responding when required. Anticipating eventual use of disjunctive responding in semiautomated systems, it is important to have an indication that an operator "is not only informed, but is also actively involved and alert" (Price, 1985, p. 39). This assumes an equal motivational level regardless of response requirement. One indication of such adequate involvement would be overall low error rates on all involved tasks, especially low omission type errors on tasks with a disjunctive response requirement. The data from Experiment 1 were examined and showed uniformly low error rates. Additionally, strong converging evidence for adequate task involvement would be gained by demonstrating an attentional demand in the case of a no-go stimulus. As the no-go situation is replacing what was formerly a response requiring stimulus in a choice situation, evidence of continued task involvement when no response is required, at least in terms of resource demand, is important. Whether or not this can be demonstrated would depend upon where in the encoding-central processing-responding sequence dual-task interference occurs. If interference is caused early in the sequence, the no-go situation may result in interference to the other task; if

late in the sequence, no interference would be observed. A demonstration of interference between tasks when one of the tasks was disjunctive and a no-go situation would support the hypothesis that no-go stimuli do demand attention and resource use.

The evidence, although equivocal, generally places interference effects at the latter stages of processing. Karlin and Kestenbaum (1968) and Keele (1970, 1973) place all the interference effect at response initiation. Their research demonstrated simultaneous, non-interfering processing up to responding with interference occurring only when responses were coincident. Kantowitz and his colleagues (Herman & Kantowitz, 1970, Kantowitz, 1974; Kantowitz & Knight, 1974, 1976) also support the hypothesis of interference primarily in the response stages of processing, although they found some evidence of stimuli, requiring no responses, causing interference. However, as no-go stimuli do not require an overt response, the Keele and Kantowitz positions would generally support the prediction of no interference from a no-go stimulus.

Despite the emphasis on the response stages as the source of interference, there is some evidence there could be measurable costs involved with no-go stimulus processing. Both the Keele and, to a lesser extent, Kantowitz positions would indicate that at least encoding and perhaps central processing are cost free in terms of resource consumption, a position originally taken by Posner and Boies (1971). Using more sensitive paradigms, however, measurable costs associated with encoding have been demonstrated (Johnson, Forester, Calderwood, & Weisgerber, 1983; Johnson & Kidd, 1984, Paap & Ogden,

1981). Therefore, there should be a measurable cost involved in processing a no-go stimulus as processes including encoding are involved in the no-go decision. As Keele and Kantowitz's work did not use secondary measures of task demand, these smaller non-response centered effects may have been eclipsed by much larger response effects. Experiment 2, however, will use a primary-secondary paradigm (Kerr, 1973) in order to have an indirect, but sensitive measure for the costs involved in not responding to a no-go stimulus.

Experiment 2 employs a letter matching task and a probe tone task. The letter matching task is designed to model a monitoring task in which there is more than one type of no-go stimulus. Subjects see a continuously changing series of 0, 2, or 5 letters occupying any of the 9 positions in a 3 x 3 array. Subjects have to respond only to two-letter-same displays. The secondary task involves a single probe tone presented 50, 150, or 250 msec after letter display onset. Subjects have to respond to all probe tones. However, only a small percentage of letter displays are accompanied by a tone task.

In terms of the general issue of replacing choice with disjunctive responses there are several comparisons of interest. If all dual-task interference is caused by responding, then there should only be response costs for two-letter-same displays with all other displays of 0, 2, or 5 letters showing no interference with the probe task. However, increased probe response times for four- and two-letter-different displays would indicate some non-response oriented interference and indicate a degree of operator involvement with the task.

Method

Subjects. Twenty-four subjects from the same pool as described in Experiment 1 were used. Subjects were used for a single 1-hour experimental session for which they received extra credit towards their introductory psychology course grade.

Design and procedure. The display device, letter sizes, and viewing distance used in this experiment were the same as described in Experiment 1. The letter match task consisted of a continually changing letter display of 0, 2, or 4 letters. Eighteen upper case letters were utilized, eliminating the most confusable letters for the font being used. A fixation square was displayed continuously on the CRT screen except during feedback time-outs. The letters appeared in any of nine locations (a 3 x 3 array) within the confines of the fixation square. Although there were several types of letter displays, subjects were only required to make a response to a same letter pair when two and only two letters were displayed. If a tone sounded simultaneously with a two-letter-same display, subjects were instructed to respond to the letters first (see Appendix II-B). Two-thirds of the letter displays were two letter displays, equally divided between same and different. The remaining third of the displays were evenly divided between four and zero letter displays. Letter displays changed every 2 seconds.

One-fourth of all letter displays were accompanied by a tone. The tone task was a 60 db, 700 Hz probe tone requiring a simple button press response upon occurrence. Letter-match and tone tasks were combined to create a dual-task situation. The same apparatus was used

to generate the stimuli. Tone onsets followed letter display onsets by 50, 150, or 250 msec, with equal probability. Only 8.3% of the trials included both a two-letter-same display and a tone. Subjects had 2000 msec to respond to two-letter-same stimuli commencing at display onset; similarly, they had a minimum of 1750 msec to respond to the tone. Responses after that time were counted as errors.

Feedback was provided as a time-out from the dual-task trials every 72 trials and lasted for a minimum of 10 secs. Subjects were provided with the number of correct and incorrect responses to both tasks as well as the average reaction time to each task. The first 144 trials of the experimental session were practice trials using the same display formats as the actual experimental trials. Following the second feedback break, subjects received 432 experimental trials, again with feedback breaks every 72 trials.

Two specially marked keys on a typewriter keyboard were used to record responses. Subjects were instructed to use their right index finger to respond to letter pairs and left index finger to respond to tones.

Results

In general the results did support resource demand for "no-go" stimuli, demonstrating subject involvement without overt responding. A two-factor analysis of variance (ANOVA: Letter Display x Probe Location) performed on the subject's mean probe reaction times (RT) showed a significant interaction, $F(6, 138) = 8.49$, $p < .05$. Significance levels for the ANOVA were based on the lower critical

F values obtained using the Geisser-Greenhouse lower bound estimate (see Appendix III-B, Table 10). Although the main effects for both letter display, $F(3, 69) = 49.31$, $p < .01$, and probe location, $F(2, 46) = 48.17$, $p < .05$, were also significant, the presence of the interaction constrained the discussion of the primary topics of interest, the main effects, to simple contrasts between means (see Table 5). The analysis of the Letter Display involved 12 pairwise comparisons, 4 within each level of probe location. Using a Bonferroni adjustment, the 12 pairwise comparisons made reduced the significant *p*-level to .004. Unless otherwise stated, all reported *p*-levels were significant.

In order to address the hypothesis that no-go stimuli were resource demanding, the first contrasts of interest were comparisons of zero-letter (0L) display probe RTs and two-letter-different (2D) display probe RTs. Reaction time to the probe was longer for 2D displays at all three probe locations: 50 msec, $t(23) = 5.41$, $p < .001$; 150 msec, $t(23) = 3.46$, $p = .002$; and 250 msec, $t(23) = 3.32$, $p = .002$. As would be expected due to the secondary nature of the probe task when presented in conjunction with a letter match task, two-letter-same (2S) display probe RTs were longer than 0L probe RTs for all probe locations (all *p*'s $< .001$).

The 2D and 2S display probe reaction times were also contrasted in order to show the expected response-no response difference. At the 50 and 150 msec probe locations, 2S display probe RTs were longer than 2D display probe RTs: 50 msec, $t(23) = 6.54$, $p < .001$ and 150 msec, $t(23) = 4.49$, $p < .001$. At the 250 msec probe location,

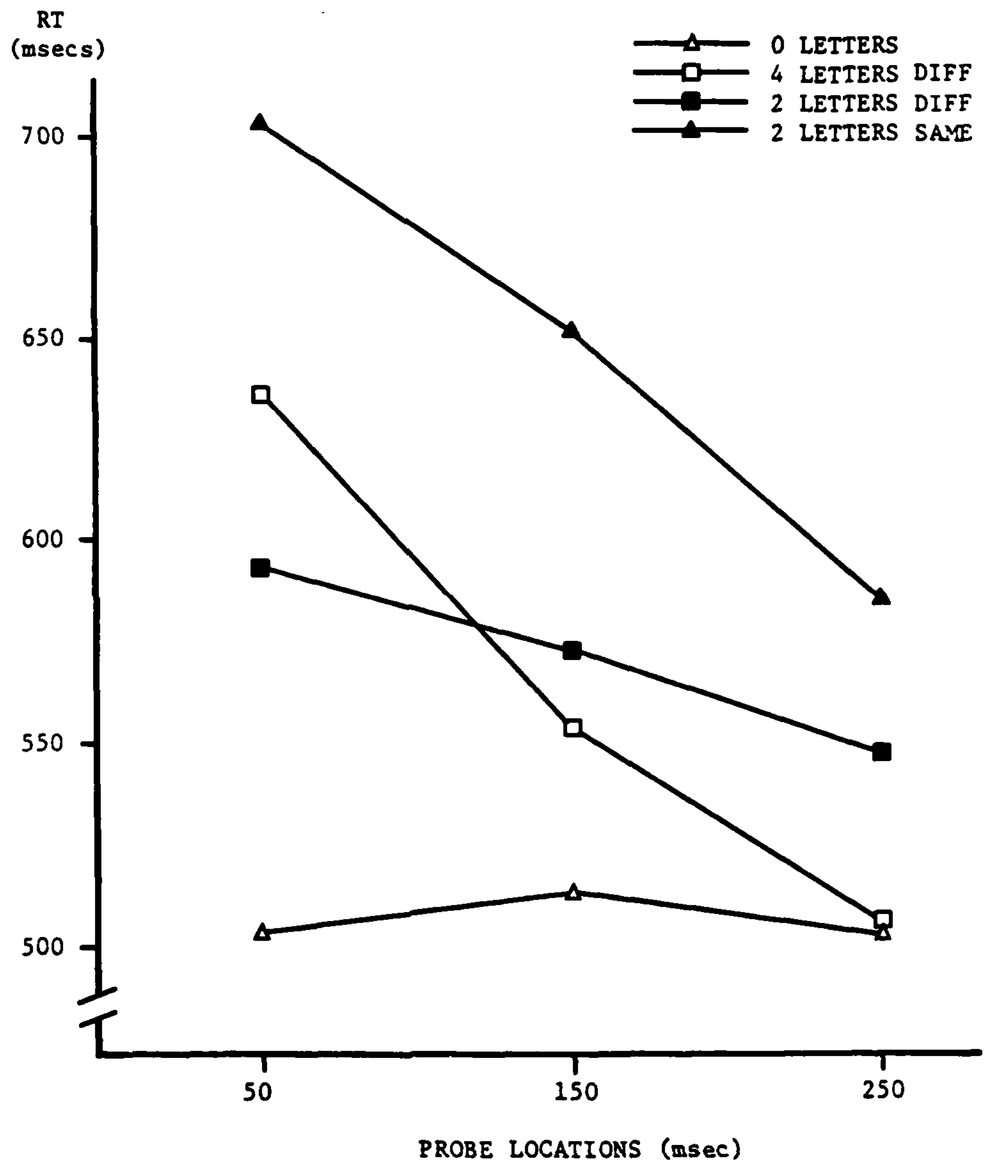

Figure 1. Plot of probe RT cell means as a function of letter display type and probe location (Experiment 2).

different rates of change in RTs across probe locations within the letter display types. Again, all p-levels are significant unless noted otherwise, with the significance p-level again being .004.

Within the 2D display condition the reduction in interference as indicated by decreasing probe RTs was significant between the 50 and 250 msec probe positions, $t(23) = 3.34$, $p = .003$, but was a relatively slow decrease. This is evidenced by the non-significant decrease between the 50 msec and 150 msec probe positions, $t(23) = 1.5$, $p = .146$ and between the 150 and 250 msec probe positions, $t(23) = 1.84$, $p = .078$. The other no-go condition, 4L, in addition to showing an overall decrease between the 50 and 250 msec probe positions, showed a much larger rate of decrease across probe locations. For the 4L condition the values were: 50 and 150 msec probe locations, $t(23) = 3.83$, $p < .001$; 150 and 250 msec probe locations, $t(23) = 3.27$, $p = .003$; and 50 and 250 msec probe locations, $t(23) = 7.34$, $p < .001$.

The rate of decrease in probe RTs with increasing delays in probe presentation followed the same pattern for 2S displays as for the 2D and 4L displays. Again the values for 2S displays showed a rapid rate of decrease: 50 and 150 msec probe location, $t(23) = 5.27$, $p < .001$; 150 and 250 msec probe location, $t(23) = 6.05$, $p < .001$; and 50 and 250 msec probe location, $t(23) = 7.31$, $p < .001$. As would be expected from an examination of the means, no differences existed relative to probe location for 0L displays (all t's < 1, all p's < .1).

Errors and letter-match response times. Extremely low error rates were observed for both the tone task, less than 0.12%, and the

letter-match task, less than 1.2%. The errors that occurred on the tone task were all on 2D trials. On the letter-match task, 6% of the errors were omission errors, 52% were commission errors on 2D trials, and the remaining 42% were commission errors on 4L and 0L trials.

There was no difference in letter-match response times with or without a concurrent probe tone, $\underline{t}(23) = 0.87$, $\underline{p} = .394$. This indicated that the letter-match task maintained primacy throughout the experiment.

Discussion

It appears that the present results support the hypothesis that presentation of no-go stimuli is resource demanding and can cause interference with a concurrent task. To the extent that resource demand of the no-go task was interfering there is some indication of subject involvement that was not response connected. This interference effect was quite persistent over time when the no-go stimuli were two letters and therefore more similar to the go stimuli. In the 4L case where the no-go stimuli were dissimilar, interference effects decline sharply with increasing task asynchrony such that the interference effect was essentially zero within as short a period as 250 msec. Although this suggests some sort of compulsory stimulus processing, subjects seemed to be able to rapidly terminate processing this class of no-go stimuli. The large probe interference in the 4L condition at 50 msec may have resulted from a subject strategy. Pilot studies indicated that including 2, 3, or 4 identical letters in the 4L displays induced large commission error rates. In executing the task, subjects may have set up a "sameness" scanning strategy,

suggested by Egeth, Marcus, and Bevan (1972), that relegated even such salient features as numerosity to a secondary status. The large interference at the 50 msec probe position may have been created by subjects scanning all four letters for a same pair despite the two-and-only-two nature of the go stimulus. In general, this suggests that stimulus complexity itself could be a stimulus property that is attention demanding over very short time spans, despite large dissimilarities to actual "go" stimuli. In contrast, the persistence of the interference effects found in the 2D displays suggests that attentional demands for other stimulus properties, such as physical similarity to the "go" stimulus, maintain stimulus control over a longer time course. Similar paradigms to the one used in this experiment may be useful in disentangling exactly what stimulus properties are resource demanding.

As to the locus of dual-task interference, this experiment provided additional strong evidence that some interference between tasks occurs outside the response stages of processing, supporting the encoding effects demonstrated in Johnson and Kidd (1983). The consistent difference between OL and 2D display probe response times and, to a lesser extent, between OL and 4L display probe response times demonstrated interference between tasks without overt responding. Additionally, the difference in the rates at which interference decreases as a function of probe delay for the 4L and 2D displays provides additional insight into the types of no-go displays that would demand the most operator attention to the task. The large difference in probe response times between OL and 2S displays and

the generally longer probe response times on 2S displays as compared to 2D displays also provided additional support for response stage interference. The observed decline in interference with increasingly delayed probe onsets would be predicted by both non-response (suggested here) or response oriented (Kantowitz & Knight, 1974, 1976; Keele, 1973) interference models as more of the possible or actual letter-match responding would be completed by probe occurrence.

GENERAL DISCUSSION

This research was conducted in order to ascertain whether or not replacing a choice response with a disjunctive response within a dual-task environment would result in reduced operator workload. The faster response times and lower error rates observed on tasks tested were taken as evidence of this reduced workload and agree with the subjective judgments gained from post-experimental discussions with subjects. The results of Experiment 1 were conclusive as to the speed and accuracy superiority of disjunctive responding within a dual-task environment. Experiment 2 demonstrated adequate operator task involvement despite the decreased response density inherent in disjunctive responding. What remains to be discussed is whether or not the superiority of disjunctive responding is of a large enough magnitude to support additional studies in more naturalistic and complex workload conditions.

In Experiment 1, the overall DRT speed advantage for the tone and letter task was 84 and 51 msec respectively, representing a 13% and a 9% time savings. By themselves, these small gains would not provide a strong argument for either an immediate change to disjunctive type responses or perhaps even further research. However, there are some qualifications that may change this conclusion. First, referring to Tables 2 and 3, disjunctive responses routinely had about one-half the error rate as choice responses. Even though these error rates are very low, Pachella (1974) has argued that within the low error rate range of operation, very small changes in errors can result in large

RT changes. Because error rates and response times are positively correlated in Experiment 1, a reduction of choice responding error rates to the level of disjunctive error rates could result in significantly larger choice RTs and dual-task CRT-DRT differences more in line with the 100 msec advantage found by Hick (1952). Even then, disjunctive responding would only be about a 15% to 17% improvement over choice responding for the two tasks. In light of the fact that there is a limited number of events that could be changed to disjunctive responding without a loss of transmitted information, even this larger gain may not provide sufficient impetus for further research and/or change.

What provides a stronger argument for change is the superior performance on the concurrent task when paired with an already faster and more accurate disjunctive task. Careful inspection of Tables 2 and 3 reveals that not only is a given task RT faster when paired with a disjunctive concurrent task, but that the advantage in having a disjunctive concurrent task pairing can be so extreme that it results in a better CRT than DRT. For example, the CRT for the letter task paired with a disjunctive tone task is 449.2 msec (non-coincident) as compared to a DRT for the letter task paired with a choice tone task of 495.8 msec (non-coincident). This same situation exists for the tone task. In other words, the small DRT speed advantage found in Experiment 1's dual-task situation is at least partially a result of a large shift in resources away from the disjunctive task. Although it cannot be clearly determined from the current experimentation whether or not only specific resources (e.g.,

those used to control physical responding) or more general resource savings occur as a consequence of disjunctive responding, it is evident that resources are readily shifted across tasks. At this point, it makes more sense to talk about a DRT advantage, rather than a speed advantage, as more than decreased RTs are occurring. It is not clear whether or not disjunctive responding actually involves fewer processes (Donders, 1868/1969); it is clear that disjunctive responding requires fewer resources and could be construed to be a different process than choice responding. As a practical consideration, the combination of faster RTs with disjunctive responding, improved performance with disjunctive pairings, and lower disjunctive error rates all suggest real promise for generally superior performance with disjunctive responding integrated into even more complex multitask environments. The use of disjunctive responding, especially during those short junctures where the operator is overloaded, would provide a partial solution to the overall workload problem.

The results of Experiment 1, within the realm of resource shifting, also introduce a theoretical issue with regard to single (e.g., Kahneman, 1973) or multiple (e.g., Navon & Gopher, 1979; Wickens, 1983) resource theories. In this experiment, resources were shared between a visual and an auditory task. Although this would seem to support a general resource model, both tasks required a motor response so that all resource sharing might have occurred within a specific motor response resource pool. Although this experimentation does not provide unequivocal support for either position, it does provide evidence that response resources are not tied to any particular task

and are, in that sense, more general.

With the demonstration that disjunctive responding requires less resources, the outcome of Experiment 2 is particularly pertinent. The reduced response density resulting from a shift to disjunctive responding to solve short term overload problems may modify the task to more of a monitoring function known to be an error prone task for human operators (Mackworth, 1969). According to Mackworth and Parasuraman and Davies (1976), the high error rates associated with monitoring or vigilance tasks is related to a lack of operator involvement. Key to the practicability of changing to disjunctive responding is whether or not task familiarity gained by an unchanged stimulus density is sufficient to alleviate monitoring problems (Dykes & Pascal, 1981; LaBerge & Tweedy, 1964) or if the decreased response density actually creates the monitoring situation (Gravetter, 1976; Hawkins, Holley, Friedin, & Cohen, 1973). In the two dual-task combinations used in this experimentation, the low error rates associated with the disjunctive responses, even lower than the choice responses, seems to indicate that maintaining the stimulus density in a fairly complex dual-task situation is sufficient to maintain adequate operator task involvement over longer time courses. The fact that operators are involved is directly supported by Experiment 2 results, that demonstrate resource demands even during no-go stimulus presentations. Thus, the converging evidence from the two experiments demonstrates that the introduction of disjunctive responding does not create a monitoring situation. However, whether or not a monitoring situation in more extreme conditions (e.g., 95% no-go stimuli) can be

avoided remains to be examined.

Experiment 2 also has some theoretical implications with regard to the issue of dual-task interference. Kantowitz and his colleagues (Herman & Kantowitz, 1970; Kantowitz & Knight, 1974, 1976) and Keele (1970, 1973) have stated that there will not be interference between tasks without overt response conflicts. (This is actually a stronger statement by Keele as the Kantowitz position has included response preparation as part of responding, although it is generally limited to motor code activation.) Experiment 2, with both the 4L and 2D stimuli, unequivocally demonstrated interference on one task without a response being required on the concurrent task. It could be argued, however, that the nature of the task demands that the subject always be prepared to respond, a cost that has already been demonstrated by Gottsdanker (1975). However, given the dissimilar appearance of the 4L stimulus to a 2S stimulus along with its very high dual-task cost at the 50 msec probe location (see Figure 1), an encoding effect as well as a possible preparation cost seems to be included in the observed dual-task interference. This would seem to indicate that Kantowitz observation of an interpolated 2S stimulus causing interference to the R1 response in a psychological refractory period experiment may have been caused by more than response preparation. Although it is not perfectly clear whether encoding and/or general preparedness were the cause of the response delay in the current experimentation, it seems clear that more than the preparation to make or actually making an overt response can cause dual-task interference.

In conclusion, the results of this study, investigating the possible use of disjunctive responding in multitask environments, are promising. The resource reallocation that occurs by changing only one task to a disjunctive response, benefiting the performance of other tasks, could remain a very important effect even in more complex environments. Coupled with a semiautomated system that allows the disjunctive response to transmit the same information to the system as a choice response, changes to disjunctive responding could provide another option for reducing workload. If the findings from this experimentation maintain in more complex paradigms, changes to disjunctive responding, where possible, would be warranted.

REFERENCES

Broadbent, D. E., & Gregory, M. (1962). Donders' b- and c-reactions and S-R compatibility. Journal of Experimental Psychology, 63, 575-578.

Comstock, E. M. (1973). Processing capacity in a letter-matching task. Journal of Experimental Psychology, 100, 63-72.

Donders, F. C. (1969). Over de snelheid van psychische processen. Onderzoeberigen gedaan in het Psyiologish Laboratorium der Uterechtsche Hoogeschool: 1868-1869. Tweede Reeks, 11, 92-120. Translated by W. G. Koster in W. G. Koster (Ed.), Attention and performance II. Acta Psychologica, 30, 412-431.

Dykes, J. R., Jr., & Pascal, V. (1981). The effect of stimulus probability on the perceptual processing of letters. Journal of Experimental Psychology: Human Perception and Performance, 7, 528-537.

Egeth, H., Marcus, N., & Bevan, W. (1972). Target-set and response-set interaction: Implications for models of human information processing. Science, 176, 1447-1448.

Gottsdanker, R. (1975). The attaining and maintaining of preparation. In P. Rabbitt & S. Dornic (Eds.), Attention and performance V. New York: Academic Press.

Gravetter, F. J. (1976). Stimulus uncertainty and reaction time for identification and recognition. Perceptual and Motor Skills, 42, 1151-1158.

Grice, G. R., Canham, L., & Schafer, C. (1982). Role of the response in associative interference. Bulletin of the Psychonomic Society, 20, 214-216.

Grice, G. R., Hunt, R. R., Kushner, B. A., & Nullmeyer, R. (1976). Associative processes and strategies in disjunctive reaction time. Memory and Cognition, 4, 433-445.

Grice, G. R., Nullmeyer, R., & Spiker, V. A. (1982). Human reaction time: Toward a general theory. Journal of Experimental Psychology: General, 111, 135-153.

Hawkins, H. L., Mackay, S. L., Holley, S. L., Friedin, B. D., & Cohen, S. L. (1973). Locus of the relative frequency effect in choice reaction time. Journal of Experimental Psychology, 101, 90-99.

Herman, L. M., & Kantowitz, B. H. (1970). The psychological refractory period: Only half the double stimulation story? Psychological Bulletin, 73, 74-89.

Hick, W. E. (1952). On the rate of gain of information. Quarterly Journal of Experimental Psychology, 4, 11-26.

Johnson, P. J., Forester, J. A., Calderwood, R., & Weisgerber, S.A. (1983). Resource allocation and the attentional demand of letter encoding. Journal of Experimental Psychology: General, 112, 616-638.

Johnson, P. J., & Kidd, S. (1984). Direct and indirect sources of secondary task interference. Unpublished manuscript. University of New Mexico.

Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.

Kantowitz, B. H. (1974). Double stimulation. In B. H. Kantowitz (Ed.), Human information processing: Tutorials in peformance and cognition (pp. 83-132). New York: John Wiley.

Kantowitz, B. H., & Knight, J. L., Jr. (1974). Testing tapping time sharing. Journal of Experimental Psychology, 103, 331-336.

Kantoqitz, B. H., & Knight, J. L., Jr. (1976). Testing tapping time-sharing II: Auditory secondary task. Acta Psychologica, 40, 343-362.

Karlin, L., & Kestenbaum, R. (1968). Effects of the number of alternatives on the psychological refractory period. Quarterly Journal of Experimental Psychology, 20, 167-178.

Keele, S. W. (1970). Effects of input and output modes on decision time. Journal of Experimental Psychology, 93, 157-164.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades: Goodyear.

Kerr, B. (1973). Processing demands during mental operations. Memory and Cognition, 1, 401-412.

LaBerge, D., & Tweedy, J. R. (1964). Presentation probability and choice time. Journal of Experimental Psychology, 68, 477-481.

Mackworth, J. F. (1969). Vigilance and habituation: A neuro-psychological approach. Baltimore: Penguin.

McCormick, E. J., & Sanders, M. S. (1982). Human factors in engineering and design (5th ed.). New York: McGraw-Hill.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. Psychological Review, 86, 214-225.

Nickerson, R. S. (1971). 'Same'-'different' response times: A further test of a 'counter and clock' model. Acta Psychologica, 35, 112-127.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Ogden, W. C., Martin, D. W., & Paap, K. R. (1980). Processing demands of encoding: What does secondary task performance reflect? Journal of Experimental Psychology: Human Perception and Performance, 6, 355-367.

Paap, K. R., & Ogden, W. C. (1981). Letter encoding is an obligatory but capacity-demanding operation. Journal of Experimental Psychology: Human Perception and Performance, 7, 518-528.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. H. Kantowitz (Ed.), Information processing: Tutorials in performance and cognition (pp. 41-82). Hillsdale, NJ: Erlbaum Associates.

Parasuraman, R., & Davies, D. R. (1976). Decision theory analysis of response latencies in vigilance. Journal of Experimental Psychology: Human Perception and Performance, 2, 578-590.

Posner, M. I., & Boies, S. J. (1971). Components of attention. Psychological Review, 78, 391-408.

Price, H. E. (1985). The allocations of functions in systems. Human Factors, 27, 33-45.

Rabbitt, P., Clancy, M., & Vyas, S. (1977). After-effects of responding and of withholding responses in CRT tasks. Quarterly Journal of Psychology, 29, 425-436.

Spiker, V. A. (1978). The effects of stimulus intensity and intensity differences on simple and disjunctive reaction time: A variable criterion analysis. Unpublished doctoral dissertation, University of New Mexico, Albuquerque.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. Acta Psychologica, 30, 276-315.

Van Cott, H. P., & Kincaid, R. G. (1972). Human engineering guide to equipment design (rev. ed.). New York: McGraw-Hill.

Weiner, E. L. (1980). Midair collissions: The accidents, the systems, and the realpolitik. Human Factors, 22, 521-533.

Weiner, E. L. (1985). Beyond the sterile cockpit. Human Factors, 27, 75-90.

Wickens, C. D. (1983). Engineering psychology and human performance (pp. 291-334). Columbus, OH: Chas. E. Merrill.

Woodworth, R. S., & Schlosberg, H. (1954). Experimental psychology (pp. 8-42). New York: Henry Holt.

APPENDICES

APPENDIX I

LITERATURE REVIEW

Disjunctive Reaction Time

Early research. The disjunctive reaction time (DRT) referred to as Type c by Donders (1868/1969), involves the reaction time to two stimuli where only one requires any action. This is differentiated from Donders' Type a reaction time, which is simple reaction time (SRT) to just one stimulus, and Donders' Type b reaction time, which is choice reaction time (CRT) to two or more stimuli each of which requires some action. Donders ordered the three reaction time tasks based on the hypothesized number of mental processes required. The SRT task was viewed as only involving the detection of the stimulus and a response. More complex was DRT which additionally required differentiation between the go and no-go stimuli. Most complex was CRT which added the final requirement of response selection, one response for each class of stimuli.

In Donders' serial-stage model of information processing, this hierarchy allowed simple subtractions of the various reaction times to determine the time required by the mental processes involved. This predicts, given a certain set of stimuli, that SRTs should always be faster than DRTs which, in turn, should be faster than CRTs. This does, however, assume what Pachella (1974) and Sternberg (1969) call pure insertion. To have pure insertion requires the characteristics of each processing stage remain constant and

unchanged regardless of the number of other stages or operations that are included in a particular response sequence. For example, encoding some material in preparation to make a simple reaction time response (Type a) would be the same as the encoding necessary to make a go/no-go response (Type c) despite the existence of a stimulus discrimination step in the latter. Both Pachella (1974) and Egeth, Marcus, and Bevan (1972) cite evidence for the response requirements influencing the encoding process which argues against pure insertion and would make predictions about response times much more difficult. What remains of Donders' ideas is that increased processing of information, which may be subdivided into stages, results in increased response times. Although Donders' original formulations for separating the time required for certain mental operations may not encompass all aspects of the reaction time process, the speed advantage of making a disjunctive response over a choice response has been repeatedly supported by empirical evidence in numerous studies.

In support of Donders' contention that DRT should be faster than CRT, Hick (1952), using the same two stimuli in both choice and disjunctive conditions, found a 100 msec speed advantage for a disjunctive response. This was an important finding as Broadbent and Gregory (1962) later showed that a meaningful disjunctive advantage may be limited to situations involving only two classes of stimuli. If more than two stimuli are used in both the choice and disjunctive conditions, the disjunctive time advantage could be attributable to both a possible reduction in the number of stimuli discriminated, due to a change in scanning strategy, as well as a reduction of the number

of response choices. Whereas it may be possible to truly replace a two-item choice task with a disjunctive task, the cverall reduction in the information processed between the disjunctive and choice situations with more than two stimuli makes true substitution improbable. Broadbent and Gregory found, however, that the speed advantage of the disjunctive task is minimized if the responses to the stimuli are highly compatible with the stimuli (e.g., the finger stimulated is the one which has to press the key). They conclude, however, that besides that case of extremely compatible stimuli and response, disjunctive does have the speed advantage.

Locus of the effect. Given the reaction time advantage of a disjunctive task over a choice task in a two stimuli situation, where is the locus of the effect? According to Rabbitt, Clancy, and Vyas (1977), the advantage of the disjunctive response is in preparing for only one motor response thereby demanding less response generation resources. The subject's decision is then reduced to deciding if it is a go or no-go trial type without the necessity of generating different response motor codes for the different responses. This hypothesis is supported by the finding that CRTs are facilitated by the repetition of a given response more than are DRTs, indicating that a change in response represents a more dramatic change in the choice task. That is, the advantage in always being able to prepare to make the same response in the disjunctive case is a viable strategy regardless of the last response made. Therefore, the repeated response advantage is minimized in the disjunctive situation, giving a strong indication that the disjunctive speed advantage is a result of

decreased response processing requirements.

Contrary to the conclusions reached by Rabbitt et al. (1977), there is evidence which indicates the total speed advantage of DRT over CRT may not reside in the response demands alone. Egeth and his colleagues (Egeth, Atkinson, Gilmore, & Marcus, 1973; Egeth & Blecker, 1971; Egeth, Marcus, & Bevan, 1972) found conflicting evidence indicating a possible change in the type of encoding as a function of the response requirements of the task. This may indicate that the disjunctive speed advantage is more significant than a mere change in the number of responses. Egeth and Blecker (1971, Experiments 1, 2, and 3) investigating the effects of familiarity on same/different judgments, found no encoding differences for same versus different judgments. This maintained when they changed response requirements from choice to disjunctive, resulting in an overall reaction time decrease. Pachella (1974), however, found evidence supporting the hypothesis that differing response requirements may effect the encoding strategy employed. For example, knowing you must only respond to a same condition in a letter-matching task may influence the type of information you encode. That is, a bias is formed towards "sameness" which allows the subject to disregard other information that may have been critical if a response to different letter pairs was also required. Pachella further hypothesized that a type of specific feature analysis is utilized in the encoding process to rapidly search for "sameness" sufficient for a match and subsequent same judgment. Egeth et al. (1972), using a Sternberg task, found empirical evidence in support of the Pachella position. Egeth et al. had subjects

memorize a list of stimuli that they had to compare against a target stimulus given later, requiring a judgment as to whether the target was a member of the memorized set. Initially, the target set included only the number 1. Then the target set was extended to either 1, 2, and 3 which they called a natural extension or 1, 4, and 7 which they called an unnatural extension. Both disjunctive responses, where a response was made only if the target was in the set, as well as choice responses were tested. As compared to the single-item memory set, disjunctive responses took 4 msec longer for the natural extension set and 48 msec longer for the unnatural extension. In choice trials (comparing only "yes" responses for consistency with the disjunctive trials), responses took 70 msec longer for the natural extension and 90 msec longer for the unnatural extension. Egeth et al.'s interpretation was that the difficulty of having to make two responses (choice situation) as well as remembering the stimulus/response relationships involved and/or the effort required to hold an unnatural stimulus set in memory decreases the resources available for encoding the target. Conversely, the ease of disjunctive responding and of remembering a natural extension to the original target set leaves more resources available at encoding that contribute to the disjunctive speed advantage. That is, the disjunctive speed advantage is a product of both simpler response requirements and a changed encoding process.[1]

In subsequent research aimed at clarifying the above process, Egeth et al. (1973, Experiment 1) compared disjunctive and choice response requirements in a visual search task, but in this experiment

found no evidence indicative of a change in encoding due to the changing response requirements. This research was supported by Blake, Fox, and Lappin (1970). Blake et al. used a letter-match task employing both upper and lower case letters in a test of interaction between stimulus type and response requirements (CRT and DRT). They found the response time differences were due only to differences in the encoding/central processing requirements with no evidence of any interaction with response requirements. Although the various findings of Pachella, Egeth and his colleagues, and Blake et al. are equivocal as to the locus of the disjunctive speed advantage, it is important to note for the current research that all the findings do support the speed superiority of disjunctive responding. Other experimental evidence suggests the ambiguity of the findings with regard to the changes in encoding due to response requirements may be due to strategies employed by subjects, consciously or unconsciously, to selected types of tasks and not to others.

Grice's additions. Although the research previously mentioned generally indicates the speed superiority of disjunctive reactions over choice reactions in the two stimuli case, more recent work by Grice and his colleagues indicate that realization of the advantage actually depends on various subject and stimulus factors (Grice, Hunt, Kushner, & Nullmeyer, 1976; Grice, Nullmeyer, & Spiker, 1982; Spiker, 1978). According to Grice, subject strategies are a major determining factor in the emergence of disjunctive speed superiority. In general, a response occurs when sufficient excitatory tendencies, resulting from the processing of sensory information, reach some normally distributed

decision criterion level. The excitatory strength is based on detection information, a function of stimulus intensity (Spiker), and on associative strength. Associative strength, in turn, is based on two factors: (a) inhibition to incorrect response tendencies, and (b) discrimination, which decreases the tendency towards response generalization. The growth of both inhibition and discimination are a function of time. Associative inhibition tendencies to the incorrect stimulus begin immediately upon stimulus onset whereas associative strength to the positive stimulus begins to accrue after 200 msec. Both of these factors, detection and association, are employed in the choice situation. In the disjunctive case, however, the use of detection alone or a combination of detection and association depends on the strategy of the subject. Grice found subjects in a disjunctive condition who adopted a detection strategy had reaction times only slightly slower than SRT. This slightly slower speed was due to the elevation of the criterion level in order to provide some inhibition to the incorrect stimulus. Subjects in the same experiment who adopted an associative strategy, however, had reaction times based on the same factors as subjects in a choice response manipulation, using both associative strength and detection. Therefore, DRT does not necessarily have a speed advantage over CRT, at least in the single-task environment, being dependent on a strategy selected by the subject.

Strategy selection in the single-task environment is both a result of the task situation and the preference of the individual subject (Grice et al., 1976). For example, Grice found that highly dissimilar

stimuli within the task eliminated stimulus generalization with respect to the positive stimulus, making the associative strategy less viable. Grice also found that if subjects set a high enough criterion level for responding due to an accuracy demand, users of the inhibition strategy may respond by detection alone. Intense stimuli would allow the setting of a high response criterion level. Therefore, in order to influence the adoption of the detection strategy in the current dual-task situation, easily detectable and/or obviously different stimuli were used. However, these stimulus manipulations, which are actually influencing the encoding activities, may or may not result in a detection strategy depending upon task selection. Grice, Canham, and Schafer (1982) found no evidence for a detection strategy in disjunctive trials when the stimuli were letters in a flanker task instead of the tones used in the earlier experiments. In this case, the disjunctive speed advantage decreased from the 100 msec range found by Hick (1952) to a 30 to 80 msec range. This indicates that even with the same encoding strategy as the subjects in the choice situation, subjects in the disjunctive situation still respond more quickly, indicating some response-centered effects. The decrease in the reaction time advantage does, however, suggest some encoding effects and the desirability of encouraging a detection strategy, if possible, for the largest disjunctive speed advantage.

Although Grice, Nullmeyer, and Spiker (1982) found subject strategies that decreased the disjunctive speed advantage, Nickerson (1971) had previously found subject strategies resulting in longer disjunctive reaction times than choice reaction times. In his

experiment, Nickerson had subjects judge two successively presented tones as the same or different. The two tones were from a total pool of six tones of frequencies 1001.1, 1004.0, 1010.1, 1022.5, 1044.9, and 1092.8 Hz. Labeling the two tones A and B, four possible combinations were presented: AA, AB, BA, and BB. Finding disjunctive responses longer than choice responses, Nickerson hypothesized a strategy of reconsidering a no-go stimulus by the subjects. If subjects reconsidered a withheld response and subsequently made the response, the resulting average disjunctive response time might exceed the choice response time due to a few extraordinarily long reaction times. This is supported by the finding that subjects made three times the number of commission errors as omission errors on the disjunctive task. The unusual finding of CRT being faster than DRT may, however, be an artifact of the experimental task used and not be widely generalizable. Recall that Grice et al. (1976) also found subjects using several different strategies when they employed a tone task. This may indicate that there is some greater degree of uncertainty with tone tasks than with letter-matching tasks which encourages strategy construction. Furthermore, although the maximum hertz difference used in this study approaches the 100 Hz difference in tones in the Rabbitt et al. (1977) study which found a DRT advantage, the various combinations of tones averaged far less than that making the Nickerson discrimination more difficult. This is supported by the overall error rate of .17 in the Nickerson study as compared to the approximately .01 error rate in the Rabbitt et al. study. The increased difficulty of the task makes the encoding of the information

the predominant event that overshadows the response effects. Additionally, the single disjunctive task, given an initial no-go response, provides a unique opportunity to reconsider the decision which, given the difficulty of the task, may have encouraged the reconsideration strategy. What the Nickerson finding does point out is the necessity for using easily discriminable stimuli in order not to confound a test of response differences with a much stronger, unrelated encoding difficulty effect. This is further supported by Grice, Nullmeyer, and Spiker's (1982) conclusion that easily discernable stimuli decrease subject strategy variability.

Summary. The question of interest in the current research is whether or not, given a variety of possible subject strategies, the disjunctive speed advantage can be demonstrated in a dual-task environment. Despite the differences in strategy selection as a function of task type and discriminability of stimuli, the demands of the dual-task environment may force subjects to adopt more time efficient detection strategies than those found in the Grice et al. (1976) and Nickerson (1971) tone-task studies. However, the question remains as to whether or not the consistent disjunctive speed advantage so well documented in single-task research will be robust to multitask manipulations. There is some evidence that it will. Comstock (1973) did find a speed advantage of 117 msec for SRT over DRT in a dual-task paradigm which compares favorably with the historic speed advantage of SRT over DRT, approximately 100 msec, in the single-task environment (Donders, 1868/1969; Woodworth, 1938; Woodworth & Schlosberg, 1954). This would seem to indicate that

whatever causes the speed advantage in the first place maintains in combination with another task. In the case of DRT versus CRT, a large DRT speed advantage is expected if the resource demands of a second task do not allow the latitude to either wait for the buildup of associative strength or the time to reconsider a no-go response. Finally, the strategy selected by the subject and the resultant reaction time may be influenced by the amount of practice he or she has had in some particular combination of tasks. That is, they may learn to be more efficient through the selection of a less resource-demanding strategy.

Models of Human Capacity and Multitask Environments

In the previous discussion of disjunctive versus choice reaction time, there was some evidence suggesting that the disjunctive speed advantage may lie in the encoding end of the encoding-processing-responding sequence as well as in the responding stage. In order to more fully address the theoretical implications and uses of a disjunctive response requirement within a multitask environment, a brief review of human information processing theories is in order. Although from an applied viewpoint, a finding that the disjunctive speed advantage maintains in a multitask situation may be sufficient, support for a particular theory of human information processing resources would also be of interest. First, without specifically addressing the disjunctive issue, some prominent information processing theories will be discussed. This will then be followed by specific predictions that the theory groups would make concerning disjunctive responding.

<u>Early theories: The single channel</u>. The readily apparent limitation of humans to process information led early theorists such as Broadbent (1958) to propose an information processing system that was limited to single channel capacity. In such a system, at a given moment in time, only a single source of information could be processed excluding other sources of incoming information from all but minimal sensory processing. It was hypothesized that other sources of input could be momentarily held in a short-term sensory buffer for later processing. Broadbent, postulating an early filter model, assumed the physical nature of the incoming stimuli predisposed the system to process certain types of information over other types thus determining the order of processing. In such a queuing system, much information would never get processed into long-term memory before it was lost from the sensory store. This became the primary reason for limited human performance in information processing.

Initially, Broadbent's (1958) theory was based on the evidence collected in a series of experiments conducted by Cherry (1953) and supported by his own research (Broadbent, 1954, 1956). In Cherry's experiments, subjects were given dichotic presentations of aural material, different messages being presented to each ear. In order to focus attention on only one ear, subjects were required to verbally shadow one of the messages. When later tested over material that had been presented to the non-attended (no shadowing) ear, subjects showed virtually no recall at all for the material. This was taken as support for the exclusive and serial nature of information processing outlined by the single channel models. It also supported the idea that the

physical nature of the signal (e.g., the information coming from the left ear) determined what incoming information got processed. However, other dichotic listening experiments began to show that some information from the unattended channel was indeed being processed beyond the sensory stage. In an experiment by Treisman (1960), subjects shadowing a story being presented to one ear were able to continue shadowing the same story even when it was unexpectedly shifted to the other ear while the originally shadowed ear was presented a new story. Many subjects did not even realize that the ear receiving the story had been switched. This indicated to Treisman that the content of the message of the unattended channel was being processed to the extent that semantic knowledge of it was available to make the rapid switch between the channels. Treisman (1964) subsequently modified Broadbent's (1958) theory by including the idea of attenuation instead of exclusion of information on the non-primary channel. She contended that although the primary channel does demand most of the single channel capacity, an attenuated signal from other channels is still being processed through the semantic level.

Although the Treisman extension of the Broadbent theory did increase the explicative power of the early filter model, further dichotic listening experiments began to support, as a minimum, a late filter model. Deutsch and Deutsch (1963) originated the idea that all information is processed in parallel through the point of perceptual analysis, but is then filtered into a single channel with only one source of information continuing into the response selection and execution stages of processing. Strong support for this late filter

model came from a study by Corteen and Wood (1972). Initially, they conditioned a list of city names to electrical shock until the presentation of the city names produced a reliable galvanic skin response (GSR). Corteen and Wood found that when the city names were presented to the unattended channel in a typical dichotic listening experiment, GSRs were again produced even though the subjects often had no conscious recollection of the mention of the city names. In fact, GSRs were produced to city names not in the original conditioning set which indicated processing well into the semantic level. These findings substantially weakened the early filter models while still supporting the possibility of a single channel processing system.

There were, however, some problems with the dichotic listening experiments in general that did not allow a definitive statement about the nature of information processing limitations. There was really no way to ensure that a highly practiced subject's total attention was captured by the shadowed channel and that they were not switching occasionally to the usually unattended channel. Such rapid switching allowing the sampling of other channels of information could be used to explain findings such as Corteen and Wood (1972), but cannot displace the possibility of a general parallel processing model. Additionally, the research supporting the late filter models (Corteen & Wood, 1972; Deutsch & Deutsch, 1963) could also imply, in the strictest definition of single channel, some peripheral processing that did not require attention. Moreover, there was no way to show, using a single task, what the capacity requirements of a given task were, making it difficult to assess issues such as peripheral

processing and switching, thus allowing several possible explanations. Finally, there was a problem of talking about attention and where that attention was directed that was confounded with the idea of conscious awareness. As a result of these difficulties, theorists replaced the idea of attention with a focus on allocation of processing resources in an attempt to divorce information processing from conscious awareness. The problem then became one of describing and measuring where the resources were being directed and how much of them were being used (Norman & Bobrow, 1975). Similarly, the emphasis shifted away from single-channel, split-attention experimentation, which explored the limits of directed attention, towards the resource metaphor (Wickens, 1983) which seeks the limits of the divisibility of processing resources. One of the principal issues then became the question of whether or not there was more than one resource pool.

Resource models. When describing how resources are used to process information, one can take the position that there is one general, undifferentiated pool of resources that can be used for a variety of processing needs, or several independent and specific pools of resources that can be used only for their specific processing area. From the perspective of either of these positions it became important to be able to measure the resource demands of a given task. As this proved difficult in single-task experimentation, emphasis was placed on the dual-task paradigm. A decrement in performance of one or both of the tasks as compared to single-task performance was taken as an indication that attention was required to perform the tasks (Kerr, 1973).[2] Several models (e.g., Kahneman, 1973; Navon & Gopher,

1979; Norman & Bobrow, 1975) hypothesized the attentional allocation policies which governed the attention given to the various tasks. Additionally, Norman and Bobrow (1975) described the resource demands of the task that, together with some given allocation policies, adequately explained the seemingly inconsistent performance of tasks in the dual-task situation. They suggested that tasks can be in two regions of resource requirements: data-limited or resource-limited. Data-limited tasks are those where limitations of the input or the relative ease of the task result in no improvement in performance beyond that gained by some minimum allocation of resources. On the other hand, resource-limited tasks are tasks where performance is limited only by the amount of resources allocated to the task. Two tasks, both in the data-limited region of resource use, would not interfere with each other as there would be no competition for resources. This would explain perfect dual-task performance. Conversely, two resource-limited tasks in combination would show some sort of reciprocal effect on each other as they competed for resources, demonstrating dual-task interference. Additionally, the practice effect of interfering tasks becoming non-interfering with experience could be explained by the assertion that the effect of practice can lead to tasks becoming more data-limited as learning occurs. In general, two tasks performed together will only show performance decrements if the joint capacity demands of the two tasks exceed the limits of the system.

Although Norman and Bobrow's (1975) conception of task resource demands was originally conceived within a single, undifferentiated resource model, the idea can easily be extended to recent multiple

resource models (Kantowitz & Knight, 1976, McLeod, 1977; Navon & Gopher, 1979; Wickens, 1983). Multiple resource models, as stated before, posit several independent resource pools and sometimes, in addition, a central pool used to coordinate activities across other resources. Given multiple resources, dual-task interference would be expected when two tasks were both in the resource-limited region for a single type of resource (in keeping with Norman & Bobrow) or as a cost of concurrence (Navon & Gopher, 1979) when the demands put on the central controlling pool of resources exceeds capacity. Thus, both single and multiple resource pool models can explain both the lack of and the observation of dual-task interference.

Earlier, the notion of automaticity was alluded to as part of resource allocation policies. In keeping with the idea of a data-limited task (Norman & Bobrow, 1975), Posner and his colleagues (Posner & Boies, 1971; Posner & Snyder, 1975) have proposed certain automatic processes. These are processes so highly practiced as to be non-interfering and have no requirement for either resources or attention. This is very close to the concept of unconscious processing suggested by the findings of Treisman (1960) and Corteen and Wood (1972). It has since been found (Johnson, Forester, Calderwood, & Weisgerber, 1983; Ogden, Martin, & Paap, 1980), at least for a letter-matching task, some small amount of resources are required indicating letter-encoding is not truly automatic as proposed by Posner and Boies (1971). However, the demand is so small that, from either the single- or multiple-resource pool perspective, the demand on the resource system would be so slight as to be negligible.

Such nearly automatic tasks would be expected to be in the data-limited region with respect to practically all other tasks.

The foregoing discussion on single and multiple capacity information systems has ignored one additional problem in the dual-task environment. This is what Kahneman (1973) has called structural interference. Two tasks will certainly interfere with each other if there is, for example, a requirement to read two passages at the same time or respond to two separated switches at the same time with the same hand. As these are known and expected problems, the emphasis in the above discussion has been placed on what Wickens (1983) calls task similarity within the information processing part of the dual-task situation. That is, the more similar the tasks are, the more likely it is that they will require the same information processing resources and show subsequent performance decrements not related to what is more clearly simple structural interference.

Resource models and the disjunctive task. Given the disjunctive speed advantage, how would the current resource models explain this advantage? Information processing models assuming a single resource pool readily explain the disjunctive speed advantage in the single-task domain. Any change in the difficulty of the task that simplifies it (e.g., an easier response requirement) would be expected to free resources resulting in improved performance. When applied to multitask environments, though, many anomalous findings appear not easily explained by single, undifferentiated resource pool models. One such difficulty for single resource models is in explaining why the structure of the task may be a better predictor of interference

than the difficulty of the task (Wickens, 1983). Difficulty is defined as manipulations of the task that generally result in single-task changes in performance (e.g., replacing normal letters in a letter-matching task with Chinese ideograms). Structure, on the other hand, refers to changes in the task that modify the types of resources used (e.g., requiring a verbal response instead of a button press). Whereas increasingly difficult tasks would be expected to show reliably greater interference, McLeod (1977), Wickens, Sandry, and Vidulich (1983), and Logan, Zbrodoff, and Fostey (1983) have found at least one structural component, the modality of the required processing, is actually a better predictor of interference than difficulty. When the structure of the task was modified so a left hand/right hand button press response for two tasks was replaced by a button press/ voice key for the same two tasks, less dual-task interference occurred. This is readily understandable if there are several distinctive processing capacities each with its own pool of resources. A structural change in the task, resulting in a decrease in competition for common resources, would explain the decline in dual-task interference.

Another problem for the single resource models is what Wickens calls "difficulty insensitivity." This is the case where two tasks interfering with each other at one level of difficulty do not show increased interference when one of the tasks, as measured by single-task performance, is increased in difficulty. Multiple resource models could explain this situation if the dual-task interference was caused by a shared-resource processing demand between the tasks, but the increase in difficulty was in a non-shared resource. Recent

multiple resource models (Kantowitz & Knight, 1976; McLeod, 1977; Navon & Gopher, 1979; Wickens, 1983), therefore readily explain the DRT advantage in the dual-task environment. However, as a shift from DRT to CRT is a change in difficulty and not structure, single pool models could also explain the difference as long as "difficulty insensitivity" was not observed. That is, as long as the assumed disjunctive simplification resulted in decreased response latencies, single pool resource model explanations would be adequate.

In multiple resource models, separate resources are generally hypothesized within the three major stages of the information processing paradigm: encoding, central processing, and responding. If there is a disjunctive speed advantage, savings in which resource pool or pools is the locus of the effect? Kantowitz argues (Kantowitz, 1982; Kantowitz & Knight, 1974, 1976) that the most important source of dual-task interference is in the response execution and control stage of processing. Given equal tasks in all other respects, a disjunctive response would be expected to show a reaction time advantage over choice reaction time if the resource demand on the responding stage were decreased. Even then, according to Grice, Nullmeyer, and Spiker (1982), the large 100 msec advantage of disjunctive responses will occur only if the demands of the dual-task situation force subjects to adopt a detection strategy and/or stimuli are selected that encourage the detection strategy. More important, although Grice's theory does not explicitly assume processing stages, strategy selection in stimulus recognition would be assigned to the encoding stage in a stage model, supporting the

hypothesis of dual-task interference as a difficulty effect outside the response stage. This hypothesis is supported by the decreased advantage of disjunctive reaction times over choice reaction times when the stimuli are letters in a flanker task, for which subjects use an associative strategy, as compared to tone stimuli, for which subjects tended to use a detection strategy (Grice, Canham, & Schafer, 1982; Grice et al., 1976). On the basis of the Grice, Canham, and Schafer conclusion, a 100 msec advantage of DRT over CRT, even in the dual-task environment, would suggest a different encoding strategy for CRT (associative) than for DRT (detection) which implies some encoding effect. On the other hand, a 30 to 80 msec DRT advantage would tend to indicate a response only effect. However, inferencing the locus of the effect based on the time-dependent hypotheses from single-task research may be inappropriate without further study.

Even restricting the disjunctive speed advantage to the response stages does not necessarily support a single or multiple response pool model. Any kind of task simplification resulting in an increased performance could be construed to be caused by savings in a specific or a general resource pool. This means a reaction time savings, regardless of theoretical model, would still be expected on a task requiring disjunctive instead of choice responses even when paired with a demanding second task. Both would predict the resources saved in the decrease in response selection effort required by a disjunctive task would result in quicker response times on the now simplified task. Additionally, both theoretical positions would predict the performance of a task (Task A) with a certain response requirement (disjunctive or

choice), paired with another task (Task B), would change in conjunction with the response requirements of Task B. That is, the reaction time of Task A paired with a disjunctive Task B, as compared with a choice Task B, may show some decrease in reaction time if the resources not used by the easier disjunctive Task B can be shifted to Task A. This would assume that the resources saved in the decrease in response selection effort required by the disjunctive Task B can be shifted to the choice or disjunctive Task A either on a momentary basis, or a more permanent basis as the result of practice.

Other Considerations

Having addressed the issues of disjunctive response requirements and their possible speed advantage within the dual-task environment, some other issues arise as to the limits of the disjunctive speed advantage. Moreover, the no-go stimulus situation has been treated as a non-entity where in fact it may have an influence on the other task's response speed in a dual-task environment. Without an exhaustive research of the literature, a brief examination will be given to changes in response density (responses per number of tasks) as well as task density (tasks per unit time) as they effect response speed. Additionally, the influence of the no-go stimulus will be briefly discussed in terms of several recent theories addressing dual-task interference.

Probability/density. Employing disjunctive response requirements changes the nature of the probabilities of events. In the choice situation, a response is always required, although which response is required is a function of how often each event occurs, allowing for

the possibility of very low probability responses. The disjunctive response option results in a further change to the probability of a given event such that the task density and the response density become independent. Considering Hyman's (1953) discovery that, in the single-task domain, low probability events have longer reaction times than do high probability events, disjunctive responding may eventually show an increase in latency as actual responses become more infrequent. Whether or not disjunctive response requirements contribute to the rare event phenomenon depends upon the relative importance of response density (responses per number of task occurrences) and task density (tasks per unit time). It would therefore be a function of the stage of processing that the probability of an event, task or response, effects the most.

Research within the single-task domain indicates there can be probability effects with the stimulus encoding, stimulus identification, response selection, and response execution stages of processing. LaBerge and Tweedy (1964), using a color identification task, manipulated both stimulus and response probabilities by requiring one response for one color and another response for two other colors. By varying the occurrences of the different colors, response requirements and stimulus familiarity could be independently manipulated. Their findings indicate stimulus familiarity has the primary effect on the latency of responding. In other words, task probability has the greatest effect on reaction times. This finding has received considerable support over the years (Bertelson & Tisseyre, 1966; Biederman & Zachary, 1970; Dykes & Pascal, 1981)

leading to the conclusion that encoding processes are being modified to speed the processing of high probability events. However, Miller and Pachella (1973) and Pachella and Miller (1976), using a Sternberg search task for same-different letters, argue that stimulus probability has its main effect in the stimulus identification (naming) stage as well as the encoding stage. In either case the predominance of the encoding stage in probability manipulations would implicate task density and not response density as the important factor in response speed. In the disjunctive case, these findings imply the disjunctive speed advantage could be maintained at very low response rates if the event, requiring a majority of no-go responses, was sufficiently frequent.

There are, however, indications that the probability of an event is directly related to the demands placed on the response execution and response selection stages. Hawkins, MacKay, Holley, Friedin, and Cohen (1973), using a letter identification task, manipulated both task and response density. They found a direct relationship between response density and response latency, with infrequent responses resulting in longer reaction times. They also found practice and high stimulus-response compatibility tend to decrease the overall effect of probability on the speed of responding. Gravetter (1976) and Spector and Lyon (1976) further defined the relationship between probability and response density, showing the response selection stage was the critical event determining the relative speed of responding. Low requirements for response selection resulted in longer response latencies. The earlier findings by Hawkins et al.

would implicate response density as the critical factor in maintaining any disjunctive response speed advantage. The importance of the response selection stage, however, makes the distinction as to the relative importance of task or response density unclear. If selecting a no-go response is equal to selecting a go response in terms of exercising the response selection process, then task density would be critical in maintaining short response latencies. On the other hand, if the response selection sequence is initiated only when an actual response is to be made, response density would become critical in maintaining any disjunctive speed advantage.

Whether or not response density or task density is the critical factor in maintaining any disjunctive speed advantage, low density of either type in the extreme is already known to have a negative effect on response speed. At very low densities, both choice and disjunctive tasks become largely vigilance tasks which are known to have both slow and inaccurate response characteristics (Mackworth, 1969; Parasuraman & Davies, 1976). The rarity of a required response which causes a surprise effect and the resulting slower response speed could only be aided by the lower response densities for disjunctive tasks.

Cost of not responding. With both tasks within the resource-limited region (Norman & Bobrow, 1975), response decrements in speed and/or accuracy are expected when both tasks within a trial require a response. The use of disjunctive response requirements, however, raises the issue of whether or not a response will be effected in the case of being paired with a disjunctive task in the no-go mode. The early theories of information processing already reviewed (Broadbent,

1958; Deutsch & Deutsch, 1963; Treisman, 1960) did equate delays in behavioral consequences, responses, to interference within the system. The early filter models of Broadbent and Treisman would fix the point of interference as a failure within the physical feature selection process whereas the late filter model of Deutsch and Deutsch would place the interference problem at response selection or later. Given the type of paradigms that were used, though, one can only speculate what the predicted effect of a no-go stimulus would have been. More clearly defined dual-task paradigms do, however, make addressing the no-go issue easier.

The evidence, although equivocal, tends to place interference effects at the latter stages of processing. According to Keele's (1970, 1973) logogen model, the locus of interference is at the response initiation stage, with no interference occurring either at memory retrieval or at response selection. Support for his assumption comes primarily from a study by Karlin and Kestenbaum (1968), which indicated that all mental operations leading up to a response can be completed simultaneously for all stimuli. Additionally, they found that two independent responses could not be initiated simultaneously as initiation of a second response must wait until the first response is completed. This is in spite of the fact that all mental operations for the second task up to responding had been accomplished. Keele (1970), too, found further support for the hypothesis of no interference without responding. Using reaction times to conjunctions of simple stimuli (shapes and colors) as compared to reaction times to the individual stimuli, he determined that it was the complexity of the

response, not the complexity of the stimulus, that created interference. As the separate responses showed a marked increase in response times, Keele concluded there is task interference only in the case of having to initiate independent responses to stimuli, not when several stimuli call for a single response. He called this process gating, where irrelevant information, despite processing, does not interfere with a response unless it calls for a conflicting response. Although this research does strongly support the hypothesis that no-go stimuli will not cause interference, the limitation of responding in only one modality as in the two experiments above may have predetermined the outcomes which support the logogen model.[3]

Kantowitz and his colleagues (Herman & Kantowitz, 1970; Kantowitz, 1974; Kantowitz & Knight, 1974, 1976) have proposed a Response Conflict Model which also supports the idea of no interference without responding. However, the definition of the response stage is somewhat broad in that it includes response preparation, response selection, and response execution. As the disjunctive response requirement might still require response preparation for the go stimulus and response selection between the go and no-go response, but lack response execution component in the no-go situation, the Response Conflict Model could support both findings of interference or no interference in the no-go stimulus situation. A closer inspection of the Herman and Kantowitz paper, however, suggests the Response Conflict Model would predict interference resulting from a no-go stimuli. Using a standard psychological refractory period paradigm, the interval between the two stimuli was varied between 0 to 400 msec. In one

particular sequence, it was noted that the second stimulus interfered with the response to the first stimulus even though the second stimulus required no response. This could be interpreted as an encoding process interfering with a response process as the cause of the increased response latency. Although the roles of the stimuli are reversed in the current experimentation with the no-go stimulus being transmitted first, Kantowitz's theory could still support a finding of interference when combining a no-go stimulus of one task concurrent with the occurrence of another task. This is due to the emphasis placed by Kantowitz on the response selection stage, versus Keele's (1970) emphasis on the response initiation stage, which allows the selection of doing nothing in no-go situations.

The multiple resource models (e.g., Navon & Gopher, 1979; Wickens, 1983) could support either an interference or lack of interference finding for the no-go stimulus situation within a dual-task environment. If any resource pool was taxed beyond capacity by the processing of both the no-go and other task stimulus, interference in terms of extended response times would be expected. That is, the appearance of a possible go stimulus in combination with the stimulus from the other task may require enough of some critical resource to show interference despite the possible go stimulus actually being a no-go event.

Final Comments

The speed advantage of the disjunctive response over a choice response is well supported in the single-task literature. Related

dual-task literature covering the manipulation of response requirements also indicates the expected findings of Experiment 1 in the current research should be a large speed advantage for the disjunctive response requiring task. Additionally, from the perspective of either a single undifferentiated resource pool model or a multiple resource model, savings in terms of decreased latencies are expected for the second task when paired against a disjunctive versus choice first task. That is, resources can be shifted away from any task that becomes easier to the benefit of any other on-going task or event. As pure insertion of extra stages or steps is not assumed to be the only difference in processing information for a choice as opposed to a disjunctive task, the exact locus of the disjunctive speed advantage will not be clearly indicated by the current research. However, Experiment 2 is expected to give some indication as to the influence of task versus response density issues in maintaining the disjunctive speed advantage. Additionally, the costs involved in not making a response will be addressed which may provide not only an indication of the possible location of interference, but continue to provide evidence as to the locus of the disjunctive speed advantage.

Notes

[1] These findings also support the single resource pool models that are discussed in the Resource models section.

[2] Early users of the dual-task paradigms still discussed outcomes in terms of attention, with its consciousness overtones, as the key to predicting which tasks would show interference. Even with the shift to the resource metaphor, the notion of automaticity was introduced (Posner & Boies, 1971), which equates to unconscious processing. The situation is further complicated by Posner and Snyder's (1975) contention that normally automatic processes could be brought under conscious, resource-using control.

[3] By using only button-press responses, both Karlin and Kestenbaum (1968) and Keele (1970) created a response conflict problem within the realm of what Kahneman (1973) has called structural interference. Either at the motor code level or at the hand or finger movement level demands are placed by the response requirements that cause physical interference. Such interference is largely eliminated by using different response modalities for the several responses (e.g., voice and button press) (Logan, Zbrodoff, & Fostey, 1983; Wickens, Sandry, & Vidulich, 1983). Employing different modalities of responding may have largely eliminated the serial nature of responding observed in the Karlin and Kestenbaum and the Keele experiments weakening the response initiation/interference connection upon which the logogen model is based.

REFERENCES

Bertelson, P., & Tisseyre, F. (1966). Choice reaction time as a function of stimulus versus response relative frequency of occurrence. Science, 212, 1069-1070.

Biederman, I., & Zachary, R. A. (1970). Stimulus versus response probability effects in choice reaction time. Perception and Psychophysics, 7, 189-192.

Blake, R. R., Fox, R., & Lappin, J. S. (1970). Invariance in the reaction time classification of same and different letter pairs. Journal of Experimental Psychology, 85, 133-137.

Broadbent, D. E. (1954). The role of auditory localization in attention and memory span. Journal of Experimental Psychology, 47, 191-196.

Broadbent, D. E. (1956). Successive responses to simultaneous stimuli. Quarterly Journal of Psychology, 8, 145-152.

Broadbent, D. E. (1958). Perception and communication. London: Pergamon Press.

Broadbent, D. E., & Gregory, M. (1962). Donders' b- and c-reactions and S-R compatibility. Journal of Experimental Psychology, 63, 575-578.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. Journal of the Acoustical Society of America, 23, 975-979.

Comstock, E. M. (1973). Processing capacity in a letter-matching task. Journal of Experimental Psychology, 100, 63-72.

Corteen, R. S., & Wood, B. (1972). Autonomic responses to shock-associated words in an unattended channel. Journal of Experimental Psychology, 94, 308-313.

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. Psychological Review, 70, 80-90.

Donders, F. C. (1969). Over de snelheid van psychische processen. Onderzoeberigen gedaan in het Psyiologish Laboratorium der Uterechtsche Hoogeschool: 1868-1869. Tweede Reeks, II, 92-120. Translated by W. G. Koster in W. G. Koster (Ed.), Attention and performance II. Acta Psychologica, 30, 412-431.

Dykes J. R., Jr., & Pascal, V. (1981). The effect of stimulus probability on the perceptual processing of letters. Journal of Experimental Psychology: Human Perception and Performance, 7, 528-537.

Egeth, H., Atkinson, J., Gilmore, G., & Marcus, N. (1973). Factors affecting processing mode in visual search. Perception and Psychophysics, 13, 394-402.

Egeth, H., & Blecker, D. (1971). Differential effects of familiarity on judgments of sameness and difference. Perception and Psychophysics, 9, 321-326.

Egeth, H., Marcus, N., & Bevan, W. (1972). Target-set and response-set interaction: Implications for models of human information processing. Science, 176, 1447-1448.

Gravetter, F. J. (1976). Stimulus uncertainty and reaction time for identification and recognition. Perceptual and Motor Skills, 42, 1151-1158.

Grice, G. R., Canham, L., & Schafer, C. (1982). Role of the response in associative interference. Bulletin of the Psychonomic Society, 20, 214-216.

Grice, G. R., Hunt, R. R., Kushner, B. A., & Nullmeyer, R. (1976). Associative processes and strategies in disjunctive reaction time. Memory and Cognition, 4, 433-445.

Grice, G. R., Nullmeyer, R., & Spiker, V. A. (1982). Human reaction time: Toward a general theory. Journal of Experimental Psychology: General, 111, 135-153.

Hawkins, H. L., MacKay, S. L., Holley, S. L., Friedin, B. D., & Cohen, S. L. (1973). Locus of the relative frequency effect in choice reaction time. Journal of Experimental Psychology, 101, 90-99.

Herman, L. M., & Kantowitz, B. H. (1970). The psychological refractory period effect: Only half the double stimulation story? Psychological Bulletin, 73, 74-89.

Hick, W. E. (1952). On the rate of gain of information. Quarterly Journal of Experimental Psychology, 4, 11-26.

Hyman, R. (1953). Stimulus information as a determinant of reaction time. Journal of Experimental Psychology, 45, 188-196.

Johnson, P. J., Forester, J. A., Calderwood, R., & Weisgerber, S. A. (1983). Resource allocation and the attentional demand of letter encoding. Journal of Experimental Psychology: General, 112, 616-638.

Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.

Kantowitz, B. H. (1974). Double stimulation. In B. H. Kantowitz (Ed.), Human information processing: Tutorials in performance and cognition (pp. 83-132). New York: John Wiley.

Kantowitz, B. H. (1982). Channels and stages in human information processing: A limited review. Unpublished manuscript.

Kantowitz, B. H., & Knight, J. L., Jr. (1974). Testing tapping time sharing. Journal of Experimental Psychology, 103, 331-336.

Kantowitz, B. H., & Knight, J. L., Jr. (1976). Testing tapping time-sharing II: Auditory secondary task. Acta Psychologica, 40, 343-362.

Karlin, L., & Kestenbaum, R. (1968). Effects of the number of alternatives on the psychological refractory period. Quarterly Journal of Experimental Psychology, 20, 167-178.

Keele, S. W. (1970). Effects of input and output modes on decision time. Journal of Experimental Psychology, 93, 157-164.

Keele, S. W. (1973). Attention and human performance. Pacific Palisades: Goodyear.

LaBerge, D., & Tweedy, J. R. (1964). Presentation probability and choice time. Journal of Experimental Psychology, 68, 477-481.

Logan, G. D., Zbrodoff, N. J., & Fostey, A. R. W. (1983). Costs and benefits of strategy construction in a speeded discrimination task. Memory and Cognition, 11, 485-493.

Mackworth, J. F. (1969). Vigilance and habituation: A neuro-psychological approach. Baltimore: Penguin.

McLeod, P. (1977). A dual task response modality effect: Support for multiprocessor models of attention. Quarterly Journal of Psychology, 29, 651-667.

Miller, J. O., & Pachella, R. G. (1973). Locus of the stimulus probability effect. Journal of Experimental Psychology, 101, 227-231.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. Psychological Review, 86, 214-255.

Nickerson, R. S. (1971). 'Same'-'different' response times: A further test of a 'counter and clock' model. Acta Psychologica, 35, 112-127.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. Cognitive Psychology, 7, 44-64.

Ogden, W. C., Martin, D. W., & Paap, K. R. (1980). Processing demands of encoding: What does secondary task performance reflect? Journal of Experimental Psychology: Human Perception and Performance, 6, 355-367.

Pachella, R. G. (1974). The interpretation of reaction time in information-processing research. In B. H. Kantowitz (Ed.), Information processing: Tutorials in performance and cognition (pp. 41-82). Hillsdale, NJ: Erlbaum Associates.

Pachella, R. G., & Miller, J. O. (1976). Stimulus probability and same-different classification. Perception and Psychophysics, 19, 29-34.

Parasuraman, R., & Davies, D. R. (1976). Decision theory analysis of response latencies in vigilance. Journal of Experimental Psychology: Human Perception and Performance, 2, 578-590.

Posner, M. I., & Boies, S. J. (1971). Components of attention. Psychological Review, 78, 391-408.

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. I. Solso (Ed.), Information processing and cognition: The Loyola symposium. Hillsdale, NJ: Erlbaum Associates.

Rabbitt, P., Clancy, M., & Vyas, S. (1977). After-effects of responding and of withholding responses in CRT tasks. Quarterly Journal of Psychology, 29, 425-436.

Spector, A., & Lyons, R. D. (1976). The locus of stimulus probability effect in choice reaction time. Bulletin of the Psychonomic Society, 7, 519-521.

Spiker, V. A. (1978). The effects of stimulus intensity and intensity differences on simple and disjunctive reaction time: A variable criterion analysis. Unpublished doctoral dissertation, University of New Mexico, Albuquerque.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. Acta Psychologica, 30, 276-315.

Treisman, A. M. (1960). Contextual cues in selective listening. Quarterly Journal of Experimental Psychology, 12, 242-248.

Treisman, A. M. (1964). Verbal cues, language, and meaning in selective attention. American Journal of Psychology, 77, 206-219.

Wickens, C. D. (1983). Engineering psychology and human performance (pp. 291-334). Columbus, OH: Chas. E. Merrill.

Wickens, C. D., Sandry, D. L., & Vidulich, M. (1983). Compatibility and resource competition between modalities of input, central processing, and output. Human Factors, 25, 227-248.

Woodworth, R. S. (1938). Experimental psychology (pp. 298-339). New York: Henry Holt.

Woodworth, R. S., & Schlosberg, H. (1954). Experimental psychology (pp. 8-42). New York: Henry Holt.

APPENDIX II-A

EXPERIMENT 1--SUBJECT DIRECTIONS

General Directions

In this experiment you will be doing two different tasks. Both of the tasks are equally important and you should attempt to do each task as quickly and accurately as possible. Although each task is relatively simple, doing both simultaneously may be quite challenging.

Now, a little more information about the two tasks. One is a letter classification task involving the two letters: X and O. Letters will be presented on the screen in front of you, within the confines of a box defined by four "+" signs. Precisely how you are to respond will change for each of the four experimental sessions so I will reserve that description for later. The other task is a tone classification task, high or low. Tones will be presented over earphones. Response requirements for the tone task will also change on a session basis.

Approximately every 2½ minutes feedback will be provided for the task or tasks. You will see your average response times and percent errors. Try to improve your response times while maintaining a low error percentage.

Before doing both tasks together, you will get to practice each task alone. The next instructions will describe the response requirements for this session.

Tone Task Instructions for Choice Tone Task

For this session, you will respond to both the high and low tones. Specially marked keys on the lower right hand row of the keyboard will be used. Use your right index finger on the key specially labeled "H" to respond to the high tone; use your right middle finger on the key marked "L" to respond to the low tone. Do this each time a tone sounds.

These single task trials are to familiarize you with the current response requirements, but are also part of the experiment. Again, please try to respond as quickly and accurately as possible. Feedback will be provided as previously described.

Tone Task Instructions for Disjunctive Tone Task

For this session you will respond to only the high tone. The specially marked key on the lower right hand row of the keyboard will be used. Use your right index finger on the key specially labeled "H" to respond to the high tone. Do this each time the high tone sounds.

These single task trials are to familiarize you with the current response requirements, but are also part of the experiment. Again, please try to respond as quickly and accurately as possible. Feedback will be provided as previously described.

Letter Task Instructions for Choice Letter Task

For this session, you will respond to both X's and O's. Specially marked keys on the lower left hand row of the keyboard will be used. Use your left middle finger on the key marked "O" to respond to the

letter "O"; use your left index finger on the key marked "X" to respond to the letter "X". Respond in this manner each time an "X" or an "O" appears.

These single task trials are to familiarize you with the current response requirements, but are also part of the experiment. Again, please try to respond as quickly and accurately as possible. Feedback will be provided as previously described.

Letter Task Instructions for Disjunctive Letter Task

For this session, you will respond to just the X's. The specially marked key on the lower left hand row of the keyboard will be used. Use your left index finger on the key marked "X" to respond to the letter "X". Respond in this manner each time an "X" appears.

These single task trials are to familiarize you with the current response requirements, but are also part of the experiment. Again, please try to respond as quickly and accurately as possible. Feedback will be provided as previously described.

Dual Task Instructions

Now that you have practiced each of the tasks alone, you are now going to be able to try your hand at doing both tasks together. Sometimes both tasks will occur at the same time, but sometimes a task will occur by itself. Neither task is more important than the other, so try to respond as quickly and as accurately as possible to both tasks. As the tasks occur in a moderately rapid sequence, attempt to complete your responding while the tone and/or letter is still present.

You will respond to each task exactly as you practiced that task in the single task sessions. Use the same specially marked keys that you did before for responding. Again, feedback will be provided but this time will include both the tasks.

APPENDIX II-B

EXPERIMENT 2--SUBJECT DIRECTIONS

In this experiment you are going to be doing two different tasks at the same time. One task is slightly more important than the other which provides you with an answer as to which task to do first if they occur at the same time. Both speed and accuracy are important to your performance score.

Now for more details. The first and most important task is a letter matching task. You you see TWO AND ONLY TWO letters which are the SAME you should respond by pressing the specially marked "S/T" key. The other task is a tone task; when you hear a tone you should respond by pressing the specially marked "T-B" key. These key markings will be explained a little later. First, a little more about the two tasks.

Tones will be presented to you over the headsets you will be wearing. Respond when you hear a tone. The letter task is slightly more complex. A box will be constantly displayed on the screen within which the letters will appear. Letter displays will change continuously at a preset rate. 0, 2, or 4 letters may appear at a time, distributed in a random fashion, within the confines of the box. However, you only respond when a two letter display appears, and then ONLY if the two letters are the same.

And now for the scoring. In order to provide you with some idea of how you are doing, the tasks will be renamed to resemble an

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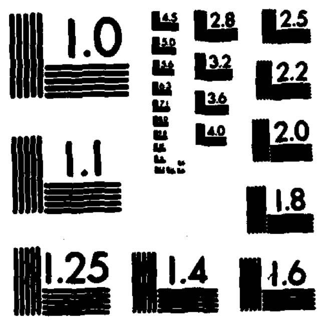

MICROCOPY RESOLUTION TEST CHART
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arcade game. For the letter match task, 2-LETTER DISPLAYS showing the SAME letters will be called "turkeys"--hence the key marked "S/T" for "same/turkey." All other letter displays (no letters, 2 letters that are different, and 4 letter displays) can be considered other types of birds that are out of season and should not be shot. Your task is to shoot turkeys as quickly as you can whenever they appear. This turkey hunt is, however, complicated by your friend who brought along a kennel full of dogs. Tones will be considered a dog bark, hence the key marked "T-B" for "tone-bark." When a dog barks, you can quiet the dog down by pressing the "T-B" key so the dog doesn't scare off the turkeys. However, following the logic of the game, you'd still want to shoot a turkey first before silencing a dog bark if they happened at the same time.

Renaming the tasks makes it easy to tell you how you are doing. At regular intervals you will see a display, a scoreboard, that looks like the following:

TURKEY TASK

	TURKEYS	OTHERS
SHOT	XX	0
NOT SHOT	0	XX

AVERAGE TURKEY SHOOT TIME: ??? MSECS

DOG BARK TASK

AVERAGE BARK REACTION TIME: ??? MSECS
NUMBER OF BARKS NOT SILENCED: ??

For the turkey task you would like to see the numbers in the positions marked "XX" indicating the number of turkeys you shot and the number of other birds you, thankfully, did not shoot. You would

also like to see zeros in the positions marked "0" which represent the number of other birds shot as well as the number of turkeys missed. Your average time to shoot the turkeys and the information on the dog bark task are self-explanatory. Times are given in thousandths of seconds so 500 msecs = 1/2 second.

Please use your right index finger to respond to the turkey (2 letters same) task and your left index finger to respond to the dog bark (tone) task. Again, let me emphasize that both speed and accuracy are important on both tasks. If you find yourself making a lot of mistakes, slow down. Additionally, the turkey task should take precedence over the dog bark task although both should be done as quickly and accurately as possible. The best response time and accuracy can be obtained by using only a single key press each time it is required. Multiple key presses or holding the key down continuously will result in increased errors and/or longer response times.

One additional bit of feedback will be provided on all tasks requiring a response. The letters will disappear either when you respond or when the next display occurs. Tones will stop once you respond to them.

The first 5-6 minutes of this task is practice. These practice trials will be the same as the actual experimental trials. If you have any questions, please ask them now as the next space bar press will start the experiment.

APPENDIX III-A

EXPERIMENT 1—ADDITIONAL TABLES

Table 6

Analysis of Variance: Practice Effect Over Days (Experiment 1)

Source of Variation	Sum of Squares	df	Mean Square	F	Sig. of F
Days	9,966.2	3	3,322.1	0.32	.81
Error	465,114.1	45	10,332.9		

Table 7

Analysis of Variance: Task x CRT/DRT x CRT/DRT Concurrent Task, Non-coincident Trials (Experiment 1)

Source of Variation	Sum of Squares	df	Mean Square	F	Sig. of F
Task	191,425.8	1	191,425.8	43.5	< .001
Error	66,076.5	15	4,405.1		
CRT/DRT	64,710.0	1	64,710.0	22.1	< .001
Error	43,962.7	15	2,930.8		
CRT/DRT Concur	186,813.3	1	186,813.3	57.1	< .001
Error	49,053.5	15	3,270.2		
Task x CRT/DRT	3,321.1	1	3,321.1	1.1	.322
Error	47,395.6	15	3,159.7		
Task x CRT/DRT Concur	780.1	1	780.1	0.2	.630
Error	48,499.6	15	3,233.3		
CRT/DRT x CRT/DRT Concur	512.0	1	512.0	0.1	.750
Error	73,014.3	15	4,867.6		
Task x CRT/DRT x CRT/DRT Concur	2,646.3	1	2,646.3	2.1	.172
Error	19,252.9	15	1,283.5		

Table 8

Analysis of Variance: Task x CRT/DRT x CRT/DRT Concurrent Task, Coincident Trials (Experiment 1)

Source of Variation	Sum of Squares	*df*	Mean Square	*F*	Sig. of *F*
Task	56,238.2	1	56,238.2	7.6	.015
Error	111,464.6	15	111,464.6		
CRT/DRT	170,601.0	1	170,601.0	39.7	< .001
Error	64,494.7	15	4,299.6		
CRT/DRT Concur	620,080.3	1	620,080.3	131.9	< .001
Error	70,495.8	15	4,699.7		
Task x CRT/DRT	10,350.0	1	10,350.0	4.4	.053
Error	35,117.7	15	2,341.2		
Task x CRT/DRT Concur	5,012.5	1	5,012.5	2.5	.135
Error	30,087.4	15	2,005.8		
CRT/DRT x CRT/DRT Concur	15,642.4	1	15,642.4	3.5	.082
Error	67,584.5	15	4,505.6		
Task x CRT/DRT x CRT/DRT Concur	10,896.6	1	10,896.6	7.2	.017
Error	22,704.6	15	1,513.6		

Table 9

Raw Data Mean (Experiment 1)

Subject	Treatment tone/lett	Day	A	B	C	D	E	G	H	I
1	DRT/DRT	4	432	302	577	546	605	417	541	553
	DRT/CRT	3	352	297	636	802	644	557	702	612
	CRT/DRT	2	386	179	579	663	688	535	757	678
	CRT/CRT	1	410	337	719	1032	879	595	916	774
2	DRT/DRT	3	307	195	444	400	493	422	442	487
	DRT/CRT	2	325	274	520	667	528	447	488	473
	CRT/DRT	1	356	251	558	505	604	600	652	632
	CRT/CRT	4	376	239	441	712	528	537	758	546
3	DRT/DRT	2	375	243	489	501	611	443	525	624
	DRT/CRT	1	403	351	562	661	613	506	608	563
	CRT/DRT	4	396	319	533	592	596	482	701	581
	CRT/CRT	3	361	322	621	955	622	478	785	618
4	DRT/DRT	1	363	259	552	514	584	415	440	560
	DRT/CRT	4	390	319	614	706	580	392	553	543
	CRT/DRT	3	412	251	546	569	610	511	662	619
	CRT/CRT	2	439	296	601	952	694	559	836	662
5	DRT/DRT	2	286	230	443	456	464	401	537	442
	DRT/CRT	3	306	262	452	557	455	383	533	441
	CRT/DRT	1	461	269	509	560	594	490	621	584
	CRT/CRT	4	390	257	486	670	538	468	645	544
6	DRT/DRT	3	456	272	673	640	578	487	559	559
	DRT/CRT	4	541	401	754	857	737	666	763	675
	CRT/DRT	2	426	168	594	628	603	472	691	588
	CRT/CRT	1	422	293	596	712	637	483	746	622
7	DRT/DRT	1	330	278	485	535	746	453	454	613
	DRT/CRT	2	302	343	480	758	714	434	506	586
	CRT/DRT	4	347	214	453	487	692	489	761	673
	CRT/CRT	3	332	286	726	927	819	541	622	562
8	DRT/DRT	4	356	192	414	469	542	287	347	343
	DRT/CRT	1	357	277	505	562	526	375	486	465
	CRT/DRT	3	362	221	495	615	578	336	431	363
	CRT/CRT	2	385	276	556	771	640	357	463	417

Table 9 (continued)

Subject	Treatment tone/lett	Day	A	B	C	D	E	G	H	I
9	DRT/DRT	2	401	237	553	583	694	421	544	599
	DRT/CRT	3	363	319	572	771	642	412	597	581
	CRT/DRT	4	358	232	511	583	626	533	670	652
	CRT/CRT	1	454	325	800	981	905	588	684	669
10	DRT/DRT	1	338	230	442	467	568	342	340	371
	DRT/CRT	2	320	336	485	685	601	369	375	381
	CRT/DRT	3	428	221	531	531	585	488	615	489
	CRT/CRT	4	345	330	649	761	774	551	580	570
11	DRT/DRT	4	445	211	453	479	630	366	471	578
	DRT/CRT	1	328	346	578	625	613	460	559	602
	CRT/DRT	2	445	218	590	623	660	508	816	646
	CRT/CRT	3	397	293	627	929	720	533	891	711
12	DRT/DRT	3	307	230	460	477	594	409	473	563
	DRT/CRT	4	285	322	532	708	608	458	602	579
	CRT/DRT	1	331	293	553	549	591	435	655	569
	CRT/CRT	2	351	299	656	948	653	582	901	644
13	DRT/DRT	2	344	225	539	510	616	464	644	641
	DRT/CRT	4	375	277	568	717	605	411	669	586
	CRT/DRT	1	438	268	523	484	605	549	617	598
	CRT/CRT	3	334	315	537	907	654	580	976	652
14	DRT/DRT	4	384	242	466	497	525	397	548	537
	DRT/CRT	2	506	392	527	786	647	422	738	652
	CRT/DRT	3	435	251	534	649	665	480	772	675
	CRT/CRT	1	422	349	689	1042	848	531	986	854
15	DRT/DRT	3	255	183	303	306	434	347	380	414
	DRT/CRT	1	271	309	464	657	529	435	503	491
	CRT/DRT	2	310	173	394	464	487	456	627	531
	CRT/CRT	4	245	241	416	664	515	414	556	460
16	DRT/DRT	1	340	279	555	585	600	478	527	637
	DRT/CRT	3	310	310	533	621	524	440	527	498
	CRT/DRT	4	344	257	618	626	542	568	730	574
	CRT/CRT	2	367	337	754	894	733	610	781	677

Note. A = Single task letter RT.
B = Single task tone RT.
C = Dual task tone non-coincident RT.
D = Dual task tone coincident versus no-go or "O" RT.
E = Dual task tone coincident versus go or "X" RT.
F = Dual task letter non-coincident RT.
G = Dual task letter coincident versus no-go or "L" RT.
H = Dual task letter coincident versus go or "H" RT.

APPENDIX III-B

EXPERIMENT 2--ADDITIONAL TABLES

Table 10

Analysis of Variance: Probe Location x Letter Display (Experiment 2)

Source of Variation	Sum of Squares	*df*	Mean Square	*F*	Critical *F*	Sig. of *F*
Probe	257,853.5	2	128,926.8	48.2	18.51	.05
Error	123,111.1	46	2,676.3			
Letter display	699,598.4	3	233,199.5	49.3	34.12	.01
Error	326,322.8	69	4,729.5			
Probe x Letter display	141,328.6	6	23,554.8	8.49	5.99	.05
Error	382,886.8	138	2,774.5			

Note. Significance is based on a conservative critical *F* value obtained through the use of the Geisser-Greenhouse lower bound estimate.

Table 11

Raw Data Means (Experiment 2)

Subject Number	Probe Location (msecs)	0 Letters Probe	4 Letters Probe	2 Letters Different Probe	2 Letters Same Probe	Letter Match Times
1	-	-	-	-	-	497
	50	390	574	485	635	531
	150	433	511	689	534	451
	250	403	419	461	475	455
2	-	-	-	-	-	642
	50	430	605	556	729	833
	150	526	550	563	666	560
	250	496	448	534	578	620
3	-	-	-	-	-	597
	50	475	576	594	625	638
	150	528	625	567	647	653
	250	593	544	564	601	591
4	-	-	-	-	-	495
	50	401	496	461	503	569
	150	426	406	415	405	469
	250	395	366	393	382	514
5	-	-	-	-	-	511
	50	474	635	555	701	500
	150	478	526	470	624	512
	250	536	416	550	514	478
6	-	-	-	-	-	642
	50	561	685	667	738	705
	150	592	637	662	724	663
	250	561	609	632	696	662
7	-	-	-	-	-	655
	50	463	722	556	737	637
	150	464	564	521	659	585
	250	452	535	505	532	604
8	-	-	-	-	-	612
	50	568	746	634	829	636
	150	556	625	650	748	646
	250	540	605	617	644	591

Table 11 (continued)

Subject Number	Probe Location (msecs)	0 Letters Probe	4 Letters Probe	2 Letters Different Probe	2 Letters Same Probe	Letter Match Times
9	-	-	-	-	-	606
	50	507	556	632	683	711
	150	509	468	555	689	643
	250	426	473	534	656	589
10	-	-	-	-	-	673
	50	537	641	604	758	647
	150	541	555	581	648	586
	250	549	603	665	548	524
11	-	-	-	-	-	632
	50	484	537	722	679	569
	150	438	601	557	675	605
	250	451	467	533	559	652
12	-	-	-	-	-	622
	50	453	730	494	639	600
	150	421	513	515	605	551
	250	436	414	414	571	558
13	-	-	-	-	-	574
	50	561	729	599	765	602
	150	514	571	609	646	557
	250	636	543	611	597	572
14	-	-	-	-	-	638
	50	599	882	782	922	708
	150	604	686	846	834	694
	250	647	657	775	757	789
15	-	-	-	-	-	598
	50	461	522	548	700	608
	150	456	465	544	651	671
	250	507	396	489	527	624
16	-	-	-	-	-	603
	50	435	561	622	725	578
	150	439	513	558	574	607
	250	594	392	539	588	549

Table 11 (continued)

Subject Number	Probe Location (msecs)	0 Letters Probe	4 Letters Probe	2 Letters Different Probe	2 Letters Same Probe	Letter Match Times
17	-	-	-	-	-	855
	50	506	545	608	534	836
	150	632	558	546	566	941
	250	395	425	495	553	930
18	-	-	-	-	-	566
	50	482	620	500	492	705
	150	418	424	454	516	501
	250	361	384	527	547	541
19	-	-	-	-	-	564
	50	413	494	466	591	557
	150	410	408	447	493	486
	250	471	400	452	380	509
20	-	-	-	-	-	610
	50	549	600	572	636	656
	150	623	631	563	631	611
	250	576	485	590	536	626
21	-	-	-	-	-	511
	50	441	486	493	635	527
	150	517	435	504	546	431
	250	400	459	472	528	480
22	-	-	-	-	-	735
	50	711	855	656	794	752
	150	673	602	651	772	809
	250	634	755	654	792	760
23	-	-	-	-	-	686
	50	718	855	648	964	900
	150	518	625	613	931	730
	250	512	692	596	814	701
24	-	-	-	-	-	681
	50	449	537	730	859	693
	150	593	695	589	786	647
	250	501	639	487	618	744

MED

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